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The Soils of Terrebonne Parish, Louisiana

S. A. LYTLE

LOUISIANA STATE UNIVERSITY
AND AGRICULTURAL AND MECHANICAL COLLEGE
DEPARTMENT OF AGRONOMY
AGRICULTURAL EXPERIMENT STATION
DOYLE CHAMBERS, DIRECTOR

Bulletin No. 651

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[1] Former Associate Professor and Assistant Professor, respectively, Department of Agronomy, Louisiana Agricultural Experiment Station.

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The Soils of Terrebonne Parish, Louisiana

S. A. Lytle[1]

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Introduction

The continuing industrial expansion and the increasing demand for food, fiber and oil crops have resulted in an increasing demand for more detailed information about the soils of the coastal parishes of Louisiana and how those soils may be best utilized. Also, there has been an increasing interest in the use-potential of the wet lands—the coastal marshlands and swamps of the coastal parishes.

The purpose of this report is to present physical, chemical and mineralogical data on the soils of Terrebonne Parish which may serve as a basis for making predictions about the behavior of the soils when they are used for farming, engineering structures or other purposes. The detailed data are essential for making interpretations about the use suitability of the soils and for determining the proper kinds of management necessary for the most efficient uses of the soils.

The data included in this report are the result of a study of soil samples from 79 sites in Terrebonne Parish. The information presented is supplemental to that of the soil survey report of Terrebonne Parish which was published in 1960 as a cooperative project of the Louisiana Agricultural Experiment Station and the USDA, Soil Conservation Service.

Nature of the Area

Terrebonne Parish, with a land area of 890,240 acres, lies along the northern shore of the Gulf of Mexico at elevations ranging from sea level in the southern part to a maximum of 16 feet above sea level in the northwestern part of the parish. The fertile alluvial soils, mild, humid subtropical climate and a growing season of about 264 days make this an important area for growing sugarcane, rice, soybeans, corn and garden crops.

The soils used for farming occur in the northern part of the parish at elevations of 5 feet or more above sea level, and they make up slightly less than 10 per cent of the parish land area. This northern part is an area of natural levees and backswamps of alluvial sediments deposited mainly by old distributaries of the Mississippi River. Small areas of the alluvium are of Red River origin; it was deposited by Bayou Teche, an old Red River channel, and by distributaries of the Atchafalaya River. A few areas of Red River sediments occur along bayous Black and Du Large, distributaries of the older Teche subdelta system.

---

[1] Associate Professor of Agronomy, Agronomy Department, Louisiana Agricultural Experiment Station, Baton Rouge.

The area of coastal marshlands and swamps makes up more than 90 per cent of the land area of Terrebonne Parish. These wet lands lie along the shore of the Gulf of Mexico at elevations ranging from near sea level to 4 or 5 feet above sea level. They extend inland to the north, where they border areas of drier soils that are used for farming. Approximately 83 per cent of the wet lands support a dense cover of grasses, sedges, forbs and woody plants and they are classified as marshlands. About 17 per cent of the wet lands are the forested swamps, which support a dense growth of tupelogum, cypress, ash, swamp maple and swamp bay trees. The wet lands are made up of silty and clayey alluvial sediments deposited by the streams flowing into and across the marshes and swamps and by waves, tides and tidal channels. Large areas of the wet lands have a surface mantle of organic materials over the silty and clayey sediments. These wet lands have a water table at or near the surface most of the time. Some areas are inundated to a depth of 18 inches by the normal daily tides. Most areas are flooded to a depth of 10 feet or more by high tides resulting from the occasional tropical storms. The wet lands are not suitable for farming without the use of flood protection structures and intensive drainage systems.

General Properties of the Soils Used for Farming

The soils used for farming in Terrebonne Parish are dominated by the Commerce and Mhoon soils which occupy the crests and slopes of the natural levees and the Sharkey soils of the backswamps and border areas of the natural levees. These soils are developing in alluvium deposited by the Mississippi River and its distributaries. Small areas of Baldwin and Cypremort, which have developed in mixed sediments of the Red and Mississippi rivers, occur on natural levees in the northwestern part of the parish. Soils of the natural levees range in elevation from 5 feet to 16 feet above sea level. The Sharkey soils on the backswamp borders of the natural levees are at elevations ranging from 4 feet to about 6 feet above sea level.

The moderately well-drained Commerce soils have a dark grayish brown loamy surface soil and brown mottled, silt loam or silty clay loam subsoil which is underlain at 24 to 30 inches by gray mottled brown silt loam or silty clay loam. Low phases of Commerce soils occupy low, narrow natural levees that extend into the coastal marshlands. These low soils have a brown or grayish brown loamy surface layer 10 to 12 inches thick that is underlain by a silty subsoil which is gray in color due to the high water table.

The somewhat poorly drained and poorly drained Mhoon soils have a grayish brown silt loam, silty clay loam or silty clay surface layer that is underlain at about 12 to 16 inches by gray mottled, stratified layers of silt loam, silty clay loam and silty clay.

The poorly drained Sharkey soils have a dark gray or very dark gray plastic clay surface layer over a gray plastic clay subsoil and substratum.

The Commerce, Mhoon and Sharkey soils range from slightly acid to moderately alkaline in reaction.

The moderately well-drained Cypremort soils have a brown very fine sandy loam, silt loam or silty clay loam surface soil and a brown silt loam or silty clay loam subsoil which has a blocky structure and dark gray clay skins. The reaction ranges from medium acid to neutral.

The somewhat poorly drained Baldwin soils have a very dark grayish brown silt loam, silty clay loam or silty clay surface soil and a dark gray mottled brown, blocky subsoil with dark clay ped coatings. The surface soil is strongly acid to slightly acid and the subsoil ranges from medium acid to mildly alkaline in reaction.

Methods of Analysis of the Soils Used for Farming

The following methods and procedures were used in the analysis of the 10 profiles of soils used for farming.

Soil pH values were determined on moist samples at the time they were collected, using a Hellige-Truog test kit. Laboratory measurements of pH were made by the method described by Peech et al. (*8*)[1] using a glass electrode pH meter.

Organic matter was calculated by a conversion factor (C x 1.72) from organic carbon determinations as carbon dioxide in the dry combustion apparatus described by Piper (*10*).

Nitrogen determinations were essentially as described by Piper (*10*) except that two selenium granules were added to hasten digestion and to give a more complete digestion.

Exchangeable bases were determined by leaching a sample of soil with an ammonium acetate solution adjusted to pH 7.0. An aliquot of the leachate was evaporated to dryness on a hot plate. The residue was treated with nitric and perchloric acid and diluted to a volume of 100 ml with a dilute solution of hydrochloric acid. The exchangeable bases were determined on this solution by means of a Model 52C Perkin-Elmer flame photometer.

Exchangeable acidity (hydrogen) was determined by leaching a sample of soil with a solution of 0.5 *N* barium acetate adjusted to pH 7.0. The leachate was titrated to the phenopthalein end-point with 0.1 *N* sodium hydroxide.

The cation exchange capacity was calculated by summation of the extractable Ca, Mg, K, Na and H.

Phosphorus was determined by the chlorostannous-reduced molybdophosphoric blue color method in a sulfuric acid system as described by Jackson (*5*) and evaluated colorimetrically by the flame photometer.

Particle size distribution was determined by the method described by Day (*3*), and the textural classification is that defined in the Soil Survey Manual (*14*).

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[1] Italic numbers in parentheses refer to Literature Cited, page 112.

Samples of all horizons of five soil profiles were analyzed for total chemical composition by following the procedures described by Hillebrand and Lundell (*4*) and modified by Robinson (*12*) and by Shapiro and Brannock (*13*). Following a sodium carbonate fusion, the silica, iron, aluminum, titanium, manganese, calcium and magnesium were determined by quantitative methods described for the analysis of silicate rocks. Following a hydrofluoric-nitric-perchloric acid digestion, the potassium and sodium were determined with the flame photometer, and phosphorus was determined colorimetrically by the electrophotometer.

Soil samples of eight soil profiles were prepared for X-ray diffraction analysis using the method of Jackson et al. (*6*) for separating the <2 microns clay fraction. The clay fraction was saturated with magnesium following the procedure of Kunze and Templin (*7*). The samples were analyzed by Dr. G. W. Kunze, Agronomy Department, Texas A&M University, using a North American Phillips high angle goniometer model apparatus with a copper target tube. The mineral composition of the samples was estimated from the relative peak intensities of the diffraction patterns of oriented mounts. The relative quantities of clay minerals present in representative soils used for farming are given in Table 5.

In the following section, 10 profiles of soils that are used for farming are located and described. The results of the chemical and physical analyses are given for each soil profile. Additional information presented includes the results of the analysis of five of the soil profiles for the total chemical composition, and the clay mineralogical data for eight of the soil profiles. The location of each soil profile is indicated by a corresponding number on the outline map of Terrebonne Parish on pages 56-57 of this report.

DESCRIPTIONS OF SOIL PROFILES AND THEIR CHEMICAL, PHYSICAL AND MINERALOGICAL CHARACTERISTICS

Soil Profile No. 1 BALDWIN SILTY CLAY

Sampled from a level field planted to sugarcane; 1.2 miles southwest of Gibson, Sec. 10, T. 16 S., R. 14 E., Terrebonne Parish.

Ap_1[1]	0-4"	Very dark grayish-brown (10YR 3/2)[2] silty clay; fine subangular blocky structure; very firm moist. pH 5.8.
Ap_2	4-8"	Dark gray (10YR 4/1) clay mottled 30 per cent with dark yellowish-brown (10YR 4/4); platy structure, very firm moist; pH 6.5.[3]
B_{21t}	8-16"	Dark gray (10YR 4/1) clay; mottled very dark grayish-brown (10YR 3/2) and yellowish-brown (10YR 5/6); angular blocky structure; plastic wet; pH 7.0.
B_{22t}	16-30"	Mottled grayish-brown (10YR 5/2) and dark yellowish-brown (10YR 4/4) clay; angular blocky structure; plastic wet; pH 7.0.
C_g	30-42"	Gray (10YR 6/1) mottled dark grayish-brown (10YR 4/2) clay with a few mottles of reddish-brown (5YR 4/3); massive to weak angular blocky structure; plastic wet; pH 7.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	P[4] ppm	Exchangeable bases[5] Ca	Mg	K	Na	Exch. Aci-dity	CEC	Base Satu-ration %
					-----------------	meq/100 g	-----	-----	-----	-----	
Ap_1	0-4	6.2	2.7	12	15.9	6.4	.4	.3	4.0	27.1	85
Ap_2	4-8	6.5	3.8	8	19.7	4.9	.4	.6	1.8	27.5	93
B_{21t}	8-16	6.6	1.5		19.8	8.8	.5	.4	1.4	30.5	96
B_{22t}	16-30	6.8	0.6		20.8	10.6	.5	.6	0.8	33.2	98
C_g	30-42	6.8	0.7		19.5	10.4	.5	.5	1.0	31.9	97

(Continued)

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[1] Explanation of soil horizon symbols in back of the report.

[2] Colors by Munsell color notations. Colors for moist soils unless otherwise stated.

[3] The pH was determined in the field with Hellige-Truog Kit.

[4] 0.1 N HCl extractable P.

[5] Exchangeable bases were determined by leaching with ammonium acetate solution adjusted to pH 7.0. Exchangeable acidity was determined by leaching with 0.5 N barium acetate adjusted to pH 7.0.

Soil Profile No. 1 BALDWIN SILTY CLAY (Continued)

Chemical Composition of the Soil

	Ap1 0-4	Ap_2 4-8	B_{21t} 8-16	B_{22t} 16-30	C_g 30-42
	per cent				
SiO_2	66.91	64.10	63.40	63.31	62.15
TiO_2	.70	.73	.77	.70	.71
Al_2O_3	15.59	17.21	19.41	18.26	19.74
Fe_2O_3	3.89	4.80	4.66	4.92	5.63
MnO	.05	.10	.12	.09	.09
CaO	.74	.81	.91	.94	.90
MgO	1.52	1.71	1.76	1.86	1.94
K_2O	2.49	2.51	2.53	2.70	2.72
Na_2O	1.35	1.48	1.25	1.39	1.47
P_2O_5	.09	.07	.07	.09	.12
Ignition Loss	6.64	5.86	5.80	5.19	5.06
Total	99.97	99.38	100.68	99.45	100.53

Mechanical Analysis

		Particle Size Distribution			
		Size class and particle diameter (mm)			
Horizon	Depth, Inches	Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		per cent			
Ap_1	0-4	8.7	47.1	44.2	sic
Ap_2	4-8	9.8	39.6	50.6	sic
B_{21t}	8-16	9.8	37.4	52.8	c
B_{22t}	16-30	10.0	37.0	53.0	c
C_g	30-42	8.9	37.5	53.6	c

Mineralogical Characteristics of the <2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap_1	0-4	27.06	>40	10-40	10-40	<10
Ap_2	4-8	27.54	>40	10-40	10-40	<10
B_{21t}	8-16	30.45	>40	10-40	10-40	<10
B_{22t}	16-30	33.22	>40	10-40	10-40	<10
C_g	30-42	31.94	>40	10-40	10-40	<10

Soil Profile No. 2 COMMERCE SILT LOAM, LOW PHASE

Sampled in virgin area from the low natural levee of Grassy Bayou; 2 miles south of Robinson Canal; in southwestern part of T. 20 S., R. 18 E., Terrebonne Parish.

Ap	0-6"	Brown (10YR 5/3) silt loam; granular structure; friable; pH 7.0.
A-C	6-16"	Mottled brown (10YR 5/3), grayish-brown (10YR 5/2), and yellowish-brown (10YR 5/4) silt loam; weak blocky structure; friable; pH 7.5.
C_1	16-24"	Brown (10YR 5/3) mottled yellowish-brown (10YR 5/4) silt loam; weak blocky structure; friable; pH 7.5.
C_{2g}	24-42"	Gray (10YR 6/1) silt loam mottled yellowish-brown (10YR 5/6); friable; pH 8.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Exch. Acidity	CEC	Base Saturation %
							----------------meq/100 g					----------------	
Ap	0-6	7.1	1.6	.08	12.1	232	9.3	2.4	.2	.3	.6	12.8	95
A-C	6-16	7.0	0.49	.03	8.9	160	12.4	4.4	.2	.5	.9	18.4	95
C	16-24	7.6	0.63	.04	10.0		10.5	4.2	.2	.3		15.3	100

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution-Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		----------------------per cent		----------------------	
Ap	0-6	12.1	82.7	5.2	si
A-C	6-16	7.1	73.8	19.1	sil
C	16-24	15.1	70.7	14.2	sil

Mineralogical Characteristics of the <2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap	0-6	12.83	> 40	10-40	< 10	< 10
A-C	6-16	18.41	> 40	10-40	< 10	< 10
C	16-24	15.29	> 40	10-40	< 10	< 10

Soil Profile No. 3 COMMERCE SILTY CLAY LOAM

Sample from a cultivated field in sugarcane 1/4 mile northwest of Southdown Refinery, Sec. 102, T. 17 S., R. 17 E. Terrebonne Parish.

Ap_1	0-8"	Very dark grayish-brown (10YR 3/2) silty clay loam; granular structure; friable; pH 7.5.
Ap_2	8-12"	Brown (10YR 5/3) and dark grayish-brown (10YR 4/2) mottled silty clay loam; platy structure; firm moist; pH 7.0.
A-C	12-18"	Brown (10YR 5/3) silt loam mottled yellowish-brown (10YR 5/6); blocky structure; friable; pH 6.5.
C_1	18-24"	Grayish-brown (10YR 5/2) silt loam mottled yellowish-brown (10YR 5/6); weak blocky structure; friable; pH 6.5.
C_2	24-42"	Light brownish-gray (10YR 6/2) silty clay loam mottled with dark yellowish-brown (10YR 4/4); massive; friable; contains one inch and two inch lenses of silt loam; pH 7.5.

Chemical Characteristics

Hori- zon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Mg	K	Na	Exch. Aci- dity	CEC	Base Satu- ration %
							----------------meq/100 g					----------------	
Ap_1	0-8	7.0	2.55	.12	11.8	700	18.9	4.1	.5	.2	1.8	25.5	93
Ap_2	8-12	6.5	1.43	.08	10.3	280	18.7	6.2	.5	.3	1.5	27.2	94
A-C	12-18	6.8	.66	.04	9.8		11.8	4.0	.2	.2	1.3	17.5	93
C_1	18-24	6.8	.60	.04	9.9		10.1	3.4	.2	.2	.9	14.8	93
C_2	24-42	6.8	.68	.05	8.5		14.1	6.8	.4	.3	1.0	22.7	95

(Continued)

Soil Profile No. 3 COMMERCE SILTY CLAY LOAM (Continued)

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution-Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		------------per cent------------			
Ap_1	0-8	10.2	63.0	26.8	sil-sicl
Ap_2	8-12	5.2	58.5	26.3	sicl
A-C	12-18	14.6	67.1	18.3	sil
C_1	18-24	18.9	69.1	11.9	sil
C_2	24-42	9.3	61.7	29.0	sicl

Mineralogical Characteristics of the < 2 Microns Clay

Horizon .	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap_1	0-8	25.47	> 40	10-40	10-40	< 10
Ap_2	8-12	27.26	> 40	10-40	10-40	< 10
A-C	12-18	17.54	10-40	10-40	< 10	< 10
C_1	18-24	14.80	10-40	10-40	< 10	< 10
C_2	24-42	22.74	> 40	10-40	< 10	< 10

Soil Profile No. 4 COMMERCE SILT LOAM

Sampled from a cultivated field in sugarcane near Waterproof; Sec. 64, T. 17 S., R. 16 E., Terrebonne Parish.

Ap	0-10"	Dark grayish-brown (10YR 4/2) silt loam; granular structure; friable; pH 6.0.
A-C	10-16"	Dark grayish-brown silt loam mottled dark gray (10YR 4/1); weak blocky structure; friable; pH 6.5.
C_1	16-36"	Brown (10YR 5/3) silt loam, mottled yellowish-brown (10YR 5/6); weak blocky structure; friable; pH 7.0.
A_b	36-40"	Grayish-brown (10YR 5/2) silty clay loam, mottled dark gray (10YR 4/1); weak blocky structure; pH 8.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Exch. Acidity	CEC	Base Saturation %
							meq/100 g	meq/100 g	meq/100 g	meq/100 g	meq/100 g	meq/100 g	
Ap	0-10	6.4	1.59	.08	12.0	228	9.3	1.9	.2	.3	2.8	14.6	80
A-C	10-16	6.8	.78	.06	8.0	148	10.6	4.1	.3	.3	2.2	17.5	87
C_1	16-36	6.9	.36	.02	11.2		7.8	2.2	.1	.4	1.4	11.8	88
A_b	36-40	7.0	1.03	.05	12.0		14.4	7.5	.3	.2	1.6	24.0	93

(Continued)

Soil Profile No. 4 COMMERCE SILT LOAM (Continued)

Chemical Composition of the Soil

	Ap 0 - 10	A-C 10 - 16	C_1 16 - 36	A_b 36 - 40
	per cent			
SiO_2	77.46	75.65	78.67	71.09
TiO_2	.68	.74	.77	.76
Al_2O_3	9.42	11.65	9.52	14.62
Fe_2O_3	2.32	3.82	2.76	4.15
MnO	.03	.05	.03	.06
CaO	.94	1.01	1.04	1.09
MgO	.59	1.24	.91	1.42
K_2O	2.20	2.31	2.23	2.44
Na_2O	2.22	2.01	2.12	2.07
P_2O_5	.10	.09	.08	.11
Ignition Loss	3.57	1.47	1.18	2.27
Total	99.53	100.01	99.31	100.08

Mechanical Analysis

		Particle Size Distribution Size class and particle diameter (mm)			
Horizon	Depth, Inches	Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay <0.002	Textural Class
		per cent			
Ap	0-10	23.9	64.2	11.9	sil
A-C	10-16	22.1	53.7	24.2	sil
C_1	16-36	34.2	43.3	9.1	1
A_b	36-40	5.0	59.4	35.6	sicl

Soil Profile No. 5 CYPREMORT SILT LOAM

Sample from a cultivated field of sugarcane; 3 miles southwest of Gibson; Sec. 23; T. 16 S., R. 14 E., Terrebonne Parish.

Ap	0-8"	Brown (10YR 5/3) silt loam; granular structure; friable; pH 6.0.
B_{21t}	8-18"	Brown (10YR 5/3) silt loam, mottled with yellowish-brown (10YR 5/4); blocky structure; friable; pH 5.5.
B_{22t}	18-28"	Dark brown (10YR 4/3) silty clay loam; blocky structure with dark gray (10YR 4/1) clay skins on ped faces; friable to firm; pH 5.5.
B_3	28-42"	Yellowish-brown (10YR 5/6) silt loam mottled with brown (10YR 5/3); weak blocky structure; friable; pH 6.5.
C	42-50"	Dark brown (10YR 4/3) mottled brown (10YR 5/3) and gray silt loam; massive; friable; pH 6.5.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Exch. Acidity	CEC	Base Saturation %
							----------------meq/100 g----------------						
Ap	0-8	6.2	1.5	.08	10.3	86	6.1	1.0	.1	.2	3.2	10.7	70
B_{21t}	8-18	6.0	0.9	.05	10.7	131	9.3	1.6	.2	.3	3.2	14.6	78
B_{22t}	18-28	6.0	0.7	.05	8.5		12.7	2.9	.3	.3	3.1	19.3	84
B_3	28-42	6.2	0.4	.03	7.2		9.5	2.2	.2	.2	1.7	13.8	88
C	42-50	6.2	1.1	.06	11.0		14.0	3.2	.3	.3	3.2	20.9	85

(Continued)

Soil Profile No. 5 CYPREMORT SILT LOAM (Continued)

Chemical Composition of the Soil

	Ap 0 - 8	B_{21t} 8 - 18	B_{22t} 18 - 28	B_3 28 - 42	C 42 - 50
	per cent				
SiO_2	77.20	74.60	74.06	77.55	74.39
TiO_2	.54	.57	.53	.54	.55
Al_2O_3	10.28	12.23	13.40	12.01	12.54
Fe_2O_3	1.57	2.43	2.77	2.45	2.50
MnO	.04	.03	.05	.05	.05
CaO	.73	.82	.64	.60	.62
MgO	1.09	1.22	1.32	1.25	1.26
K_2O	2.15	2.28	2.20	2.23	2.35
Na_2O	1.68	1.70	1.37	1.31	1.44
P_2O_5	.07	.07	.07	.09	.09
Ignition Loss	4.06	3.45	3.17	2.42	3.86
Total	99.41	99.40	99.58	100.50	99.65

Mechanical Analysis

		Particle Size Distribution			
		Size class and particle diameter (mm)			
	Depth,	Sand	Silt	Clay	Textural
Horizon	Inches	2.0 - 0.05	0.05 - 0.002	< 0.002	Class
		per cent			
Ap	0-8	29.8	62.9	7.3	sil
B_{21t}	8-18	19.1	64.9	16.0	sil
B_{22t}	18-28	19.2	56.0	24.8	sil
B_3	28-42	37.9	46.8	15.3	l
C	42-50	17.9	59.3	22.8	sil

Mineralogical Characteristics of the <2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap	0-8	10.67	> 40	10-40	< 10	< 10
B_{21t}	8-18	14.55	> 40	10-40	< 10	< 10
B_{22t}	18-28	19.29	> 40	10-40	< 10	< 10
B_3	28-42	13.82	> 40	10-40	< 10	< 10
C	42-50	20.96	> 40	10-40	< 10	< 10

Soil Profile No. 6 MHOON SILT LOAM

Sample from a sugarcane field 6 miles south of Houma and 1/8 mile east of Bayou Du Large; Sec. 18, T. 18 S., R. 17 E., Terrebonne Parish.

Ap_1	0-8"	Dark grayish-brown (10YR 4/2) silt loam; granular structure; friable; pH 8.0.
Ap_2	8-12"	Grayish-brown (10YR 5/2) silt loam; platy structure; firm moist; pH 8.0.
C_1	12-24"	Light brownish-gray (10YR 6/2) silt loam, mottled yellowish-brown (10YR 5/4); weak blocky structure; friable; pH 8.0.
C_2	24-42"	Light brownish-gray (10YR 6.2) silt loam, mottled yellowish-brown; massive; friable; pH 8.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Mg	K	Na	Exch. Aci- dity	CEC	Base Satu- ration %
							-----------------	meq/100 g	-----------------				
Ap_1	0-8	6.3	1.46	.08	10.58	169	18.7	3.8	.2	.4	.3	23.4	99
Ap_2	8-12	7.6		.04		144	18.8	3.3	.3	.4	.0	22.8	100
C_1	12-24	7.8		.05			19.5	3.4	.3	.7	.0	23.9	100
C_2	24-42	8.1		.02			16.3	1.9	.3	.7	.0	19.2	100

(Continued)

Soil Profile No. 6 MHOON SILT LOAM (Continued)

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution-Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		------------------------per cent	------------------------	------------------------	
Ap_1	0-8	29.1	59.0	11.9	sil
Ap_2	8-12	18.5	63.6	17.9	sil
C_1	12-24	16.3	65.8	17.9	sil
C_2	24-42	22.0	68.1	9.9	sil

Mineralogical Characteristics of the < 2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap_1	0-8	23.43	> 40	10-40	10-40	< 10
Ap_2	8-12	22.75	> 40	10-40	10-40	< 10
C_1	12-24	23.88	> 40	10-40	10-40	< 10
C_2	24-42	19.18	> 40	10-40	10-40	< 10

Soil Profile No. 7 MHOON SILT LOAM

Sample from a sugarcane field on the north side of Bayou Black; 3/4 mile east of Minor's Canal; Sec. 95, T. 17 S., R. 16 E., Terrebonne Parish.

Ap_1	0-6"	Dark grayish-brown (10YR 4/2) silt loam; granular structure; friable; pH 6.3.
Ap_2	6-10"	Dark gray (10YR 4/1) silt loam mottled dark grayish-brown; platy structure; firm moist; pH 7.5.
C	10-36"	Gray (10YR 5/1) and dark gray (10YR 4/1) silt loam mottled dark grayish-brown (10YR 4/2); weak blocky structure; friable; pH 8.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Mg	K	Na	Exch. Acidity	CEC	Base Saturation %
							meq/100 g						
Ap	0-6	6.8	1.83	.103	11.15	236	15.6	4.1	.5	.6	1.1	22.0	95
Ap_2	6-10	6.7	1.73	.087	11.53	199	15.8	4.7	.4	.7	1.0	22.5	96
C	10-36	7.0	1.02	.067	8.83		17.2	5.7	.4	.6	.6	24.5	98

(Continued)

Soil Profile No. 7 MHOON SILT LOAM (Continued)

Chemical Composition of the Soil

	Ap1 0 - 6	Ap2 6 - 10	C 10 - 36
	per cent		
SiO_2	73.77	73.92	72.30
TiO_2	.72	.73	.76
Al_2O_3	10.41	12.04	13.99
Fe_2O_3	3.24	3.27	4.09
MnO	.05	.05	.05
CaO	.99	1.03	1.04
MgO	2.22	2.05	2.18
K_2O	2.46	2.35	2.46
Na_2O	1.81	2.12	1.97
P_2O_5	.08	.11	.13
Ignition Loss	3.81	3.21	1.95
Total	99.56	100.88	100.92

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution-Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		per cent			
Ap_1	0-6	13.2	69.7	17.1	sil
Ap_2	6-10	13.1	67.0	19.9	sil
C	10-36	15.5	60.1	24.4	sil

Soil Profile No. 8 MHOON SILTY CLAY LOAM

Sample from a field of sugarcane, Crescent Plantation; northwestern part of Sec. 81, T. 17 S., R. 16 E., Terrebonne Parish.

Ap_1	0-5"	Very dark grayish-brown (10YR 3/2) silty clay loam; fine blocky structure; firm moist, plastic wet; pH 6.2.
Ap_2	5-10"	Dark grayish-brown (10YR 4/2) silty clay loam, mottled with very dark grayish-brown (10YR 3/2); blocky structure; firm moist; pH 7.5.
A-C	10-16"	Dark grayish-brown (10YR 4/2) silty clay loam mottled dark yellowish-brown (10YR 4/4); massive to weak blocky structure; friable; pH 7.5.
C_{1g}	16-36"	Gray (10YR 5/1) silty clay loam, mottled grayish-brown (10YR 5/2); massive; firm moist; pH 7.5.
C_{2g}	36-42"	Gray (10YR 5/1) silty clay loam mottled with brown (10YR 5/3); massive; friable; pH 7.5.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Mg	K	Na	Exch. Acidity	CEC	Base Saturation %
							-----------------	-----	meq/100	g-----	-----	-----	
Ap_1	0-5	6.4	2.51			109	18.6	7.6	.5	.1	2.4	29.2	92
Ap_2	5-10	7.1	1.06			128	20.6	9.1	.4	.2	1.5	31.8	95
A-C	10-16	7.2	0.87			168	21.5	8.3	.4	.2	.9	31.3	97
C_{1g}	16-36	7.2	0.92			150	20.0	8.8	.5	.2	1.1	30.6	96
C_{2g}	36-42	7.2	0.70			172	16.5	7.4	.4	.2	1.0	25.5	96

(Continued)

Soil Profile No. 8 **MHOON SILTY CLAY LOAM** (Continued)

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution-Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay <0.002	Textural Class
		per cent	per cent	per cent	
Ap_1	0-5	5.1	59.9	35.0	sicl
Ap_2	5-10	4.8	57.3	37.9	sicl
A-C	10-16	6.0	60.0	34.0	sicl
C_{1g}	16-36	7.2	57.4	35.4	sicl
C_{2g}	36-42	5.1	67.8	27.1	sil

Mineralogical Characteristics of the <2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmor-illonite %	Illite %	Kaolinite %	Quartz %
Ap	0-5	29.22	> 40	10-40	10-40	< 10
Ap_2	5-10	31.79	> 40	10-40	< 10	< 10
A-C	10-16	31.25	> 40	10-40	10-40	< 10
C_{1g}	16-36	30.64	> 40	10-40	10-40	< 10
C_{2g}	36-42	25.48	10-40	10-40	10-40	10-40

Soil Profile No. 9 SHARKEY CLAY

Sampled from a sugarcane field on Crescent Plantation; Sec. 71, T. 17 S., R. 16 E., Terrebonne Parish.

Ap_1	0-8"	Very dark grayish-brown (10YR 3/2) clay; fine blocky structure; firm moist; pH 6.8.
Ap_2	8-12"	Gray (10YR 5/1) clay mottled yellowish-brown (10YR 5/4); platy structure; firm moist; pH 7.5.
C_1	12-25"	Gray (10YR 6/1) clay mottled yellowish-brown (10YR 5/4); strong blocky structure; very firm moist; pH 8.0.
C_2	25-46"	Gray (10YR 6/1) clay mottled grayish-brown (10YR 5/2) and yellowish=brown; massive to weak blocky structure; very firm moist; pH 8.0.

Chemical Characteristics

Horizon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Exch. Acidity	CEC	Base Saturation %
							---------------	---------------	meq/100 g	---------------	---------------	---------------	
Ap_1	0-8	6.2	3.31	.172	11.2	144	28.2	10.5	.9	.1	2.5	41.2	94
Ap_2	8-12	6.8	2.38	.139	10.0	78	29.2	11.6	.8	.2	2.4	44.3	95
C_1	12-25	7.6	1.25	.085	8.5	62	29.5	12.4	.8	.3	0.9	43.8	98
C_2	25-46	7.3	1.65	.088	10.9	75	27.8	12.3	.8	.3	1.5	42.7	97

(Continued)

Soil Profile No. 9 SHARKEY CLAY (Continued)

Chemical Composition of the Soil

	Ap_1 0 - 8	Ap_2 8 - 12	C_1 12 - 25	C_2 25 - 46
	per cent			
SiO_2	61.69	61.75	61.04	62.60
TiO_2	1.00	.93	.94	.85
Al_2O_3	17.91	18.82	18.87	17.75
Fe_2O_3	5.14	6.10	6.14	6.84
MnO	.11	.13	.12	.11
CaO	1.03	1.12	1.07	1.16
MgO	1.74	2.60	2.56	2.64
K_2O	2.37	2.52	2.49	2.42
Na_2O	.88	.91	1.01	.86
P_2O_5	.17	.16	.13	.15
Ignition Loss	7.99	5.63	5.52	4.93
Total	100.03	100.67	99.89	99.37

Mechanical Analysis

		Particle Size Distribution			
		Size class and particle diameter (mm)			
Horizon	Depth, Inches	Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay < 0.002	Textural Class
		per cent			
Ap_1	0-8	9.1	37.5	53.4	c
Ap_2	8-12	8.5	34.2	57.3	c
C_1	12-25	7.5	36.4	56.1	c
C_2	25-46	8.7	38.1	53.2	c

Mineralogical Characteristics of the < 2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap_1	0-8	41.21	> 40	10-40	< 10	< 10
Ap_2	8-12	44.25	> 40	10-40	< 10	< 10
C_1	12-25	43.83	> 40	10-40	< 10	< 10
C_2	25-46	42.65	> 40	10-40	< 10	< 10

Soil Profile No. 10 SHARKEY CLAY

Samples from a cultivated field in sugarcane 1 mile south of the bridge over Petit Caillou and Terrebonne bayous; south central part of Sec. 16, T. 17 S., R. 18 E., Terrebonne Parish.

Ap_1	0-3"	Very dark gray (10YR 3/1) clay; blocky structure; very firm moist; pH 6.5.
Ap_2	3-8"	Very dark gray (10YR 3/1) clay; blocky structure; pH 6.5.
A-C	8-16"	Very dark gray (10YR 3/1) clay mottled yellowish-brown (10YR 5/4); blocky structure; very firm moist; pH 7.0.
C_1	16-20"	Very dark gray (10YR 3/1) and gray (10YR 6/1) clay mottled brown (10YR 5/3); blocky structure; very firm moist; pH 8.0.
C_2	20-36"	Gray (10YR 6/1) clay mottled yellowish-brown (10YR 5/6); blocky structure; very firm moist; pH 8.0.

Chemical Characteristics

Hori- zon	Depth, Inches	pH	Organic Matter %	N %	C/N Ratio	P ppm	Exchangeable bases Ca	Mg	K	Na	Exch. Aci- dity	CEC	Base Satu- ration %
							----------------meq/100 g----------------						
Ap_1	0-3	6.2	3.15	.123	14.8	81	39.7	14.9	1.0	.5	3.2	59.1	95
Ap_2	3-8	5.9	3.09	.153	11.7	69	38.3	14.3	.9	.6	4.5	58.4	92
A-C	8-16	6.3	3.18				40.8	14.8	.9	.8	3.3	60.6	95
C_1	16-20	7.2	1.26				41.1	15.8	.9	1.6	.4	59.7	99
C_2	20-36	7.3	1.09				39.1	14.6	.9	1.6	.5	56.7	99

(Continued)

Soil Profile No. 10 SHARKEY CLAY (Continued)

Chemical Composition of the Soil

	Ap_1 0 - 3	Ap_2 3 - 8	A-C 8 - 16	C_1 16 - 20	C_2 20 - 36
	per cent				
SiO_2	59.02	59.24	58.32	58.60	61.76
TiO_2	.83	.83	.83	.86	.86
Al_2O_3	18.84	18.82	18.05	20.56	19.86
Fe_2O_3	6.55	6.65	7.40	6.70	6.96
MnO	.07	.06	.07	.13	.13
CaO	1.19	1.17	1.20	1.21	1.39
MgO	1.47	1.26	1.51	1.09	1.28
K_2O	2.69	2.63	2.58	2.63	2.77
Na_2O	1.05	1.39	1.47	1.43	1.63
P_2O_5	.15	.13	.14	.11	.09
Ignition Loss	7.74	7.55	7.63	6.32	2.74
Total	99.63	99.74	99.69	99.64	99.47

Mechanical Analysis

Horizon	Depth, Inches	Particle Size Distribution Size class and particle diameter (mm) Sand 2.0 - 0.05	Silt 0.05 - 0.002	Clay <0.002	Textural Class
		per cent			
Ap_1	0-3	13.1	26.7	60.2	c
Ap_2	3-8	10.5	27.3	62.2	c
A-C	8-16	10.8	27.0	62.1	c
C_1	16-20	11.0	25.4	63.6	c
C_2	20-36	10.6	28.1	61.3	c

Mineralogical Characteristics of the <2 Microns Clay

Horizon	Depth, Inches	CEC meq/100g	Montmorillonite %	Illite %	Kaolinite %	Quartz %
Ap_1	0-3	59.11	>40	10-40	10-40	<10
Ap_2	3-8	58.42	>40	10-40	10-40	<10
A-C	8-16	60.55	>40	10-40	10-40	<10
C_1	16-20	59.74	>40	10-40	10-40	<10
C_2	20-36	56.70	>40	10-40	10-40	<10

Chemical Properties of the Soils Used for Farming

Soil Reaction

Measurements of the hydrogen-ion concentrations (pH) of the soils show that they are generally well supplied with basic ions and slightly acid to mildly alkaline in reaction. The highest concentrations of hydrogen-ions are present in the Ap_2 horizon of profile No. 10—Sharkey clay and in the B_{2t} horizons of profile No. 5—Cypremort silt loam, and these horizons are medium acid in reaction. The subsoil and substratum horizons are generally low in hydrogen-ion content and neutral to mildly alkaline in reaction. The pH values generally increase with increasing depth in the soil profiles. The Baldwin and Cypremort soils are more acid in reaction than the Commerce, Mhoon and Sharkey soils. Profile No. 2—Commerce silt loam, low phase is neutral to mildly alkaline in all horizons.

Organic Matter Content

The content of organic matter contributes greatly to the cation exchange capacity and is usually responsible for the dark color of the surface soils. Organic matter improves the physical condition of a mineral surface soil and aids in the retention of moisture and plant nutrients. The values for organic matter distribution show that the maximum amounts are present in the surface soils or Ap horizons of all of the soils of this study, with the highest amounts, 2.3 to 3.8 per cent, in the dark colored Ap horizons of the Sharkey and Baldwin soils. The lowest amounts of organic matter are present in the B_{2t} horizons of Baldwin soil, 0.6 per cent, the A-C and C horizons of profile No. 2—Commerce silt loam, low phase, 0.49 to 0.63 per cent, the A-C horizons of profile No. 3—Commerce silty clay loam, 0.60 to 0.68 per cent, and the B horizons of the Cypremort soil, 0.04 to 0.9 per cent. The distribution of organic matter is very irregular with depth in the profiles of all the soils except the terrace soils of the Baldwin and Cypremort series. The irregular distribution of organic matter is a common characteristic of soils developing in young alluvial sediments. Recent alluvial materials with well-developed surface horizons high in organic matter are commonly found buried at depths of several feet by the subsequent deposition of sediments. An example of a buried old surface soil is the secondary maximum accumulation of organic matter or the buried A (A_b) horizon of profile No. 4—Commerce silt loam. The deep distribution of organic matter in the profiles of the clayey Sharkey soils is due in part to the shrink-swell properties of the clays. When dry, the clays contract and crack to depths of one meter or more. The dark surface soil falling into these cracks accounts for the deeper distribution of organic matter. The deep distribution of organic matter in profile No. 7—Mhoon silt loam is probably due to the presence of organic materials in the strata of alluvium in which the soil is developing.

The percentage of nitrogen present in these soils is relatively low, and most crops may be expected to respond to applications of nitrogen. The highest amounts of nitrogen are present in the Sharkey soils. The lowest amounts of nitrogen are present in the Cypremort and Baldwin soils and in the A-C and C horizons of the Commerce soils.

The carbon/nitrogen ratio is an indicator of the degree of organic matter decomposition that has taken place in the soil. Most of the soils have C/N ratios which range in values from 9 to 1 to 12 to 1. These are typical values for good farming soils.

Extractable Phosphorus

Values of 120 to 180 ppm of phosphorus are considered to be medium to high for the medium-textured alluvial soils of the Mississippi River, according to the chemical data used to interpret soil tests taken from *Fertilizer Recommendations for Louisiana* and shown in Table 1. Values for the fine-textured soils of the Mississippi River alluvium are: Low—80 ppm, Medium—160 ppm and High—160 ppm or more. Laboratory data show that the phosphorus content of the Ap horizons of medium-textured soils of this study ranges from a medium value of 86 to 131 ppm for the Cypremort soil to a higher value of 144 to 700 ppm for the Commerce soils and the profiles of Mhoon silt loam. The phosphorus content of the surface layers of the clayey soils of this study ranges from very low, 8 to 12 ppm, for the Baldwin silty clay, low, 69 to 81 ppm, for profile No. 10—Sharkey clay, and medium, 78 to 144 ppm for profile No. 8—Mhoon silty clay and profile No. 9—Sharkey clay. The report of Byrnside and Sturgis (*2*) on the response of sugarcane to soil phosphorus indicated that sugarcane growing on soils containing less than 100 ppm of extractable phosphorus usually responded to additional applications of phosphorus. Values for extractable phosphorus indicate that sugarcane grown on the Baldwin and Cypremort soils may be expected to respond to the application of additional phosphorus to a greater extent than sugarcane grown on the Commerce and Mhoon soils.

Exchangeable Cations

Laboratory results show that the positive charged basic ions (cations) of calcium, magnesium, potassium and sodium are much more abundant on the mineral and organic soil particles of the soils of this study than the positive charged acidic cations of hydrogen and aluminum. All of these cations are held by the soil particles until they are displaced or exchanged by other cations. In order to evaluate the results of this study, reference is made to the values used to interpret soil test results from *Fertilizer Recommendations for Louisiana,* and presented in part in Table 1.

Medium to high amounts of exchangeable calcium are present in most of the soils of this study. High values of 28 to 41 meq/100g soil are recorded for the clayey Sharkey soils, 15.6 to 19.5 meq/100g soil for the silty soils, profiles No. 6 and No. 7—Mhoon silt loam and the Ap horizons of profile No. 3—Commerce silty clay loam. A low amount

Table 1 .-Chemical data used to interpret soil test results.

General Soil Areas	Extractable Phosphorus ppm	Texture	Approx. CEC meq/100g	Calcium meq/100g			Magnesium meq/100g			Potassium meq/100g		
				Low	Medium	High	Low	Medium	High	Low	Medium	High
Miss. River	L*-60											
Alluvial Soils	M-120	Loam	8	5.0	5.0-6.5	6.5+	0.83	0.83-1.08	1.08+	0.25	0.25-0.36	0.36+
Med. textured	H-120+	Silt Loam	15	9.0	9.0-12.0	12.0+	1.66	1.66-2.0	2.0 +	0.41	0.41-0.51	0.51+
Miss. River	L-80	Clay loam	20	13.0	13.0-16.0	16.0+	2.16	2.16-2.6	2.6+	0.51	0.50-0.77	0.77+
Alluvial Soils		(32% clay)										
Fine textured	M-160	Clay	25	16.0	16.0-20.0	20.0+	2.6	2.6-3.3	3.3+	0.62	0.62-0.92	0.92+
		(40% clay)										
	H-160+	Clay	30	19.5	19.5-24.0	24.0+	3.2	3.2-4.0	4.0+	0.72	0.72-1.07	1.07+
		(50% clay)										
		Clay	40	26.0	26.0-32.0	32.0+	4.3	4.3-5.3	5.3+	0.87	0.87-1.3	1.3+
		(60% clay)										

Source: Fertilizer Recommendations for Louisiana. La. Agr. Exp. Sta. Cir. No. 84, p. 9, January, 1967. Louisiana State University and Agricultural and Mechanical College, Baton Rouge, Louisiana.

Values for calcium, magnesium and potassium changed from ppm to meq/100g.

*L = low; M = medium and H = high.

of exchangeable calcium, 6.1 meq/100g soil, is present in the Ap horizon of Cypremort silt loam. Medium values for exchangeable calcium, 16.5 to 21.5 meq/100g soil, are present in the Baldwin silty clay and Mhoon silty clay profiles. The silty soils having medium values for exchangeable calcium, 8.9 to 14.0 meq/100g soil, are all horizons of profile No. 2—Commerce silt loam, low phase, profile No. 4—Commerce silt loam, the A-C and C horizons of Commerce silty clay loam and the subsoil and C horizon of Cypremort silt loam. Profile No. 10—Sharkey clay has the highest values for exchangeable calcium, 38.3 to 41.1 meq/100g. The content of exchangeable calcium usually increases with depth in the soil profiles.

Most of the soils of this study are well supplied with exchangeable magnesium, and magnesium increases with depth in most of the soil profiles. High values of exchangeable magnesium, 4.9 to 15.8 meq/100g, are present in the Baldwin silty clay, Mhoon silty clay loam and the profiles of Sharkey clay. Medium to high exchangeable magnesium values are noted for the medium-textured soils of the Mhoon, Commerce and Cypremort series except for the Ap horizon of Cypremort silt loam, which has a low value.

The exchangeable potassium values for the soils of this study range from low to high, with many of the soils having very low values in relation to the data in Table 1. Low values of exchangeable potassium, 0.4 to 0.5 meq/100g of soil, are noted for the profiles of Baldwin silty clay and Mhoon silty clay loam. The clayey soils of the Sharkey series have high values of 0.8 to 1.0 meq/100g. Many of the medium-textured soils contain low amounts of exchangeable potassium. Low values of exchangeable potassium, 0.1 to 0.3 meq/100g, are present in the Commerce and Cypremort soils and in profile No. 6—Mhoon silt loam. Profile No. 7—Mhoon silt loam and the Ap horizons of profile No. 3—Commerce silty clay loam have medium values, 0.4 to 0.5 meq/100g. In general, there is an increase in exchangeable potassium with depth in the soil profiles. Most of the common crops grown on these soils may be expected to respond to applications of potassium fertilizer.

No appreciable amount of exchangeable sodium is present in the soils of this study. The highest amounts, 0.5 to 1.6 meq/100g, are present in profile No. 7—Mhoon silt loam and profile No. 10—Sharkey clay. The presence of low amounts of exchangeable sodium is a favorable characteristic of good farming soils. Soils in which the exchange capacity contains 15 per cent or more of exchangeable sodium generally have poor physical characteristics, because of the dispersion of the soil particles. The highest value for exchangeable sodium, 1.6 meq/100g, is only 3 per cent of the total cation exchange capacity of the C horizon of profile No. 10—Sharkey clay.

The values for exchangeable acidity (hydrogen plus aluminum) are generally low for most of the soils, with the highest values, 4.0 meq/100g, present in the Ap_1 horizon of Baldwin silty clay, 3.2 to 4.5 meq/100g present in the Ap and A-C horizons of profile No. 10—Sharkey clay, and 1.7 to 3.2 meq/100g in profile No. 5—Cypremort silt loam. There is a relationship between values for exchangeable acidity and the degree of soil weathering. The gradual decrease in the values for exchangeable acidity with depth in the soil profiles is noted in the profiles of the older soils of the Baldwin and Cypremort series. In profile No. 6—Mhoon silt loam, the exchange capacity is satisfied by basic cations, and the acidic cations have a very low value of 0 to 0.3 meq/100g.

Calcium-Magnesium Ratios

The soils in general are well supplied with both calcium and magnesium, and as a consequence the Ca/Mg ratios are narrow but well within the range of values considered favorable for plant growth. Soils having the widest Ca/Mg ratios are Cypremort silt loam, 4.3 to 8.5, and

Table 2.-The ratio of calcium to magnesium for all horizons of selected soil profiles

Soil Profile Name and Number	Horizon	Depth, Inches	Ca:Mg Ratios*
1. Baldwin silty clay	Ap_1	0-4	2.4
	Ap_2	4-8	4.0
	B_{21t}	8-16	2.2
	B_{22t}	16-30	1.9
	C_g	30-40	1.8
4. Commerce silt loam	Ap	0-10	4.9
	A-C	10-16	2.5
	C_1	16-36	3.5
	A_b	36-40	1.9
5. Cypremort silt loam	Ap	0-8	6.0
	B21t	8-18	5.9
	B22t	18-28	4.3
	B_3	28-42	4.3
	C	42-50	4.3
7. Mhoon silt loam	Ap_1	0-6	3.8
	Ap2	6-10	3.3
	C	10-36	3.0
8. Mhoon silty clay loam	Ap_1	0-5	2.4
	Ap_2	5-10	2.2
	A-C	10-16	2.5
	C_{1g}	16-36	2.2
	C_{2g}	36-42	2.2
10. Sharkey clay	Ap_1	0-3	2.6
	Ap_2	3-8	2.6
	A-C	8-16	2.7
	C_1	16-20	2.6
	C_2	20-36	2.6

*Calculated from meq/100g values.

profile No. 6—Mhoon silt loom, with a Ca/Mg ratio of 4.9. Soils having narrow Ca/Mg ratios are profile No. 8—Mhoon silty clay loam and the profiles of Sharkey soils, with values of 2.2 to 2.7. The other soils have Ca/Mg ratios which are intermediate in value. The lower values or narrow Ca/Mg ratios with increasing depth in the soil profiles are most evident in the older and more weathered soils of the Baldwin and Cypremort series. The Ca/Mg ratios for selected soil profiles are given in Table 2.

Cation Exchange Capacity

The capacity of a soil to hold basic and acidic cations depends mainly on the content of adsorbed basic and acidic cations, the content of organic matter and clay and the dominant minerals present in the clay. The Baldwin and Sharkey soils and profile No. 8—Mhoon silty clay loam have a clay content of 27 to 63 per cent which is dominated by montmorillonite, and an organic matter content of 0.7 to 3.8 per cent, and these soils have cation exchange capacity values ranging from 27 to 60 meq/100g. The medium-textured soils, containing lower amounts of clay and organic matter and having cation exchange capacity values ranging from 10.7 to 24 meq/100g, include Cypremort silt loam, profile No. 2—Commerce silt loam, low phase and profile No. 4—Commerce silt loam. The values for each basic and acidic exchangeable cation as per cent of the total cation exchange capacity are given for selected soil profiles in Table 3. Calcium cations dominante the cation exchange capacity and make up from 57.0 to 75.8 per cent of the total cation exchange capacity for all of the soils of this study. The highest values for exchangeable calcium as per cent of the total cation exchange capacity are 70.2 to 75.8 per cent recorded for profile No. 7—Mhoon silt loam. The percentage of the cation exchange capacity satisfied by exchangeable calcium ions is 57 per cent for the Ap horizon of profile No. 5—Cypremort silt loam.

Exchangeable basic cations of magnesium are in good supply in these soils, with values of 9.3 to 32.6 per cent of the total cation exchange capacity. The highest values are 32.6 per cent for the $\mathbf{C_g}$ horizon and 28.8 to 31.9 per cent for the $\mathbf{B_t}$ horizons of Baldwin silty clay. Other high values of exchangeable magnesium are 26 to 29 per cent of the cation exchange capacity for all horizons of the Sharkey soils.

Exchangeable potassium cations make up 0.9 to 2.27 per cent of the cation exchange capacity, with the highest value of 2.27 per cent for the Ap_1 horizon of profile No. 7—Mhoon silt loam, and the lowest value of 0.9 per cent for the Ap horizon of Cypremort silt loam. Most horizons of all the soils studied have values for exchangeable potassium of 1.3 to 1.5 per cent of the total cation exchange capacity.

Exchangeable sodium makes up only a small part of the cation exchange capacity, with values ranging from 0.3 to 3.4 per cent. The lowest values of 0.3 to 0.8 per cent are for soil profile No. 8—Mhoon silty clay loam. The highest value of 3.4 per cent is present in the C_1 horizon of profile No. 4—Commerce silt loam. The exchangeable sodium makes up 2.4 to 3.1 per cent of the cation exchange capacity for all horizons of profile No. 7—Mhoon silt loam.

Exchangeable acidity values, which include the acidic cations of hydrogen and aluminum, make up only a relatively small percentage, 0.6 to 19.2 per cent, of the total cation exchange capacity for most of the soils of this study. The highest percentage values, 12.3 to 29.9 per cent, are for all horizons of Cypremort silt loam. The lowest values of 0.6 to 1.1 per cent of the cation exchange capacity are for all horizons of profile No. 7—Mhoon silt loam. The exchangeable acidity percentage of the cation exchange capacity ranges from 0.9 to 7.7 per cent for all horizons of profile No. 10—Sharkey clay, from 2.9 to 8.2 per cent for all horizons of profile No. 8—Mhoon silty clay loam and from 6.7 to 19.2 for all horizons of profile No. 4—Commerce silt loam.

Table 3.-Values for each exchangeable cation of the exchange complex as per cent of the total cation exchange capacity for selected soil profiles.

Profile No. and Name	Soil Horizon	Depth, Inches	Percentages of the total CEC				
			Ca	Mg	K	Na	H
1. Baldwin silty clay	Ap_1	0-4	58.6	23.6	1.4	0.7	14.7
	Ap_2	4-8	70.1	17.8	1.4	1.0	6.5
	B_{21t}	8-16	64.9	28.8	1.6	1.1	4.5
	B_{22t}	16-30	62.4	31.9	1.5	0.9	2.4
	C_g	30-42	61.1	32.6	1.5	0.8	3.1
4. Commerce silt loam	Ap	0-10	63.7	13.1	1.3	2.0	19.2
	A-C	10-16	60.5	23.4	1.7	1.7	12.5
	C_1	16-36	66.1	18.7	.8	3.4	11.8
	A_b	36-40	60.0	31.6	1.25	0.8	6.7
5. Cypremort silt loam	Ap	0-8	57.0	9.3	.9	1.8	29.9
	B21t	8-18	63.7	10.9	1.37	2.0	21.9
	B_{22t}	18-28	65.8	15.0	1.55	1.5	16.0
	B_3	28-42	68.8	15.9	1.45	1.4	12.3
	C	42-50	67.0	15.7	1.43	1.4	15.3
7. Mhoon silt loam	Ap_1	0-6	70.9	18.6	2.27	2.7	1.1
	Ap2	6-10	70.2	20.8	1.77	3.1	1.0
	C	10-36	75.8	23.2	1.63	2.4	.6
8. Mhoon silty clay loam	Ap_1	0-5	63.7	26.0	1.7	.3	8.2
	Ap_2	5-10	61.6	28.6	1.3	.6	4.7
	A-C	10-16	68.6	26.5	1.3	.6	2.9
	C_{1g}	16-36	65.6	28.6	1.6	.7	3.6
	C_{2g}	36-42	64.7	29.0	1.6	.8	3.9
10. Sharkey clay	Ap_1	0-3	66.0	25.2	1.7	.9	5.4
	Ap_2	3-8	65.5	24.4	1.5	1.0	7.7
	A-C	8-16	67.3	24.4	1.5	1.3	5.4
	C_1	16-20	68.7	26.4	1.5	2.7	.7
	C_2	20-36	68.7	25.7	1.5	2.8	.9

Base Saturation

The percentage of the cation exchange capacity that is satisfied by the basic cations of Ca, Mg, K and Na is relatively high to very high for all soils of this study, ranging from 70 to 100 per cent. The Cypremort silt loam contains the lowest amounts of basic cations and has the lowest values for percentage base saturation, which range from 70 to 88 per cent for all horizons. Profile No. 4—Commerce silt loam has cation exchange capacities for all horizons which are 80 to 93 per cent satisfied by bases. The base saturation values for all other soils of this study range from 85 to 100 per cent. The base saturation values generally increase with increasing depth in the soil profiles.

Total Bases and Exchangeable Bases

The total amounts of bases present in the soils are compared with the amounts of the bases that are exchangeable. The values for the percentages of the total bases in the soils that are present as exchangeable bases are given in Table 4 for all horizons of representative soils of Terrebonne Parish.

The values for total calcium oxide range from 0.60 to 1.39 per cent of the total soil for all the soils, with the highest values of 0.94 to 1.39 per cent present in the younger alluvial soils of the Commerce, Mhoon and Sharkey series. The lowest total calcium oxide values, 0.60 to 0.91 per cent, are present in the older soils of the Baldwin and Cypremort series. The percentage of total calcium that is exchangeable ranges from 21 to 95 per cent for all the soils studied, with the highest values, 67 to 95 per cent, for the Sharkey soils and the lowest values, 21 to 37 per cent, for Commerce silt loam. The Ap horizon of Cypremort silt loam also has a low value of 23 per cent. The percentage of the total calcium that is exchangeable ranges from 43 to 63 per cent for Baldwin and Mhoon soils.

The values for total magnesium oxide in the soils are highest, 1.09 to 2.64 per cent, for the Baldwin, Mhoon and Sharkey soils and lowest, 0.59 to 2.35 per cent, for the Commerce and Cypremort soils. The percentage of the total magnesium that is exchangeable ranges from the highest values, 4.9 to 28.8 per cent, for the Baldwin and Sharkey soils to the lowest values, 1.8 to 5.1 per cent, for the Cypremort and Mhoon soils.

There is a rather uniform distribution of small amounts, 2.15 to 2.77 per cent, of total potassium oxide in all of the soils of this study, with the highest amounts, 2.37 to 2.77 per cent, in the clayey soils of Baldwin and Sharkey series. The lowest amounts of total potassium oxide, 2.15 to 2.44 per cent, are present in the Commerce and Cypremort soils. The percentage of the total potassium that is exchangeable ranges from the highest values, 1.10 to 1.80 per cent, present in the Commerce and Sharkey soils to the lowest values, 0.21 to 0.64 per cent, present in the Cypremort soil. Values for the percentage of the total potassium that is exchangeable range from 0.60 to 0.88 per cent for the Baldwin and Mhoon soils.

The total amounts of sodium oxide are rather uniformly distributed throughout the soils of this study, with the highest values, 1.81 to 2.22 per cent, present in all horizons of the Commerce and Mhoon soils. The lowest values, 0.88 to 1.63 per cent, are present in all horizons of the Baldwin and Sharkey soils. Values for total sodium oxide in Cypremort soil range from 1.31 to 1.70 per cent. The percentage of the total sodium that is exchangeable ranges in value from 0.34 to 3.47 per cent. The highest values, 1.34 to 3.47 per cent, are present in profile No. 10—Sharkey clay and the lowest values, 0.37 to 0.68 per cent, are present in profile No. 5—Cypremort silt loam.

Table 4.-The percentages of total bases in the soils that are present as exchangeable bases for representative soils.

Soil Profile Name and Number	Soil Horizon	Depth, Inches	Exchangeable bases divided by total bases			
			Ca	Mg	K	Na
			-----------	per cent	----------	
1. Baldwin silty clay	Ap_1	0-4	60.5	8.4	.75	.69
	Ap_2	4-8	55.2	4.9	.74	1.26
	B_{21t}	8-16	49.2	10.0	.88	.99
	B_{22t}	16-30	62.5	11.3	.86	1.34
	C_g	30-42	61.5	10.7	.87	1.05
4. Commerce silt loam	Ap	0-10	27.7	6.8	1.80	.35
	A-C	10-16	29.4	6.6	1.50	.68
	C_1	16-36	21.0	4.8	1.50	.92
	A_b	36-40	37.0	10.5	1.50	1.08
5. Cypremort silt loam	Ap	0-8	23.3	1.8	.21	.37
	B_{21t}	8-18	31.7	2.6	.41	.50
	B_{22t}	18-28	55.5	4.4	.64	.68
	B_3	28-42	44.3	3.6	.42	.40
	C	42-50	63.2	5.0	.60	.64
7. Mhoon silt loam	Ap_1	0-6	44.1	3.7	.80	1.03
	Ap_2	6-10	42.9	4.6	.80	1.02
	C	10-36	46.3	5.1	.60	.94
9. Sharkey clay	Ap_1	0-8	76.6	12.0	1.80	.35
	Ap_2	8-12	73.0	8.9	1.50	.68
	C_1	12-25	76.4	9.6	1.50	.92
	C_2	25-46	67.2	9.3	1.50	1.08
10. Sharkey clay	Ap_1	0-3	93.4	10.0	1.80	1.48
	Ap_2	3-8	91.6	22.6	1.70	1.34
	A-C	8-16	95.2	19.5	1.10	1.61
	C_1	16-20	94.5	28.8	1.70	3.47
	C_2	20-36	78.6	22.7	1.50	3.20

Total Analysis and Soil Profile Development

From the total soil analysis data, interpretations may be made about the amount of differentiation of soil materials into genetic soil horizons and about the degree of soil formation. The decrease in the percentage of total SiO_2 from the surface layers downward may be interpreted to indicate the removal of the fine clay particles from the upper or surface layer, leaving more particles of sand size. Since Al_2O_3 and SiO_2 are components of the clays which accumulate in the subsoil layer during soil formation, values from the total analysis data which show an increase in Al_2O_3 and a decrease in SiO_2 in the subsoil layers, when related to a moderate to strong degree of soil structure and the presence of clay-coated peds, are indications of the differentiation of the soil material into genetic soil horizons. Total analysis data for profile No. 1—Baldwin silty clay and profile No. 5—Cypremort silt loam indicate a decrease in SiO_2 and an increase in Al_2O_3 in the subsoil horizons. These two soils also have moderate to strong blocky structure and clay coatings on ped surfaces. These characteristics are the expression of a moderate degree of soil formation. Data for profile No. 7—Mhoon silt loam and profiles Nos. 9 and 10—Sharkey clay do not show significant changes in the values for Al_2O_3 and SiO_2 with depth in the profiles and they are considered to be lacking in the well-defined genetic horizons. Data for profile No. 4—Commerce silt loam indicate a slight degree of soil profile development as evidenced by a slight increase in Al_2O_3 and a slight decrease in SiO_2 in the subsoil horizon.

Mineralogical Properties of the Soils Used for Farming

The results of X-ray diffraction analysis of samples from all horizons of eight representative soils of the soils used for farming are presented in Table 5. These analyses indicate that the less than 2 microns clay fractions of the soils generally contain considerable amounts of montmorillonite and illite and lesser amounts of kaolinite and quartz minerals. Montmorillonite is the dominant clay mineral in all horizons of the Baldwin, Mhoon, Sharkey and Cypremort soils and profile No. 2—Commerce silt loam, low phase. Lesser amounts of montmorillonite are present in the A-C and C_1 horizons of profile No. 3—Commerce silty clay loam. The presence of considerable amounts of montmorillonite indicates that the soils are well supplied with basic cations. The physical condition of soils is influenced by excessive amounts of montmorillonite clay minerals which cause the soil to shrink and crack when dry and to expand when wet, and limits the usefulness of the soil for many purposes. The distribution of illite is uniform throughout all horizons of the soils studied, with the clay fraction containing 10 to 40 per cent of this mineral. The presence of moderate amounts of illite indicates that the soils contain a considerable reserve of potassium which is not readily available to plants. The values for the percentage of

Table 5.-The relative quantities of clay minerals present in representative soils used for farming.

Profile No.	Soil Type	Horizon	Depth, Inches	CEC	M*	I*	K*	Q*
					percentage			
1	Baldwin silty clay	Ap_1	0-4	27.0	> 40	10-40	10-40	< 10
		Ap_2	4-8	27.5	> 40	10-40	10-40	< 10
		B_{21t}	8-16	30.5	> 40	10-40	10-40	< 10
		B_{22t}	16-30	33.0	> 40	10-40	10-40	< 10
		C_g	30-42	32.0	> 40	10-40	10-40	< 10
2	Commerce silt loam, low phase	Ap	0-6	13.0	> 40	10-40	< 10	< 10
		A-C	6-16	18.0	> 40	10-40	< 10	< 10
		C_1	16-24	15.0	> 40	10-40	< 10	< 10
3	Commerce silty clay loam	Ap_1	0-8	25.0	> 40	10-40	10-40	< 10
		Ap_2	8-12	27.0	> 40	10-40	10-40	< 10
		A-C	12-18	17.5	10-40	10-40	< 10	< 10
		C_1	18-24	15.0	10-40	10-40	< 10	< 10
		C_2	24-42	23.0	> 40	10-40	< 10	< 10
5	Cypremort silt loam	Ap	0-8	11.0	> 40	10-40	< 10	< 10
		B_{21t}	8-18	15.0	> 40	10-40	< 10	< 10
		B_{22t}	18-28	19.0	> 40	10-40	< 10	< 10
		B_3	28-42	14.0	> 40	10-40	< 10	< 10
		C	42-50	21.0	> 40	10-40	< 10	< 10
6	Mhoon silt loam	Ap_1	0-8	23.0	> 40	10-40	10-40	< 10
		Ap_2	8-12	23.0	> 40	10-40	10-40	< 10
		C_1	12-24	24.0	> 40	10-40	10-40	< 10
		C_2	24-42	19.0	> 40	10-40	10-40	< 10
8	Mhoon silty clay loam	Ap_1	0-5	29.0	> 40	10-40	10-40	< 10
		Ap_2	5-10	32.0	> 40	10-40	< 10	< 10
		A-C	10-16	31.0	> 40	10-40	10-40	< 10
		C_{1g}	16-36	31.0	> 40	10-40	10-40	< 10
		C_{2g}	36-42	25.0	10-40	10-40	10-40	10-40

(Continued)

Table 5.-The relative quantities of clay minerals present in representative soils used for farming.
(Continued)

Profile No.	Soil Type	Horizon	Depth, Inches	CEC	M*	I*	K*	Q*
					------------percentage			--------------
9	Sharkey clay	Ap_1	0-8	41.0	>40	10-40	<10	<10
		Ap_2	8-12	44.0	>40	10-40	<10	<10
		C_1	12-25	44.0	>40	10-40	<10	<10
		C_2	25-46	43.0	>40	10-40	<10	<10
10	Sharkey clay	Ap_1	0-3	59.0	>40	10-40	10-40	<10
		Ap_2	3-8	58.0	>40	10-40	10-40	<10
		A-C	8-16	61.0	>40	10-40	10-40	<10
		C_1	16-20	60.0	>40	10-40	10-40	<10
		C_2	20-36	57.0	>40	10-40	10-40	<10

*Key to mineral composition of the <2 microns clay fraction:

Abbreviation of mineral names	Indication of Quantity
M = Montmorillonite	Abundant component $>40\%$
I = Illite	Less abundant component 10-40%
K = Kaolinite	Minor component $<10\%$
Q = Quartz	

kaolinite mineral content are 10 to 40 per cent for most horizons of the soils, with lower values of less than 10 per cent for all horizons of profile No. 2—Commerce silt loam, low phase, profile No. 5—Cypremort silt loam and profile No. 9—Sharkey clay. The A-C and C horizons of profile No. 3—Commerce silty clay loam and the Ap_2 horizon of profile No. 8—Mhoon silty clay loam also contain less than 10 per cent of kaolinite. The quartz content of the less than 2 microns clay fraction is less than 10 per cent for all of the soils. In comparing the mineral content of the C horizons or parent material with the other horizons of the soil profiles, there is an indication that the soil minerals of the soil profiles are inherited from the parent material instead of having been formed in the soils. It is probable that the differences in the amounts of kaolinite present in the two Sharkey soil profiles may be the result of differences in the mineral composition of the different stratified layers of alluvial sediments.

Physical Properties of the Soils Used for Farming

The physical properties of the soils are important in determining suitable cropping systems and the kind and degree of management necessary when the soils are used for farming. In this coastal area, one of the major properties determining the use of the soils for cultivated crops is the elevation above sea level and its influence on the height of the ground water table and on soil wetness. Soil texture is also important because of its influence on the degree of internal soil drainage. Texture also determines the ease or difficulty of seedbed preparation and other tillage operations. The soils used for farming having the most favorable physical properties are the moderately well-drained Commerce and Cypremort soils. These soils generally occur at elevations ranging from 5 to 16 feet above sea level and they are easily drained by the gravity flow of surface water in properly directed furrows. They are moderately permeable, and the water table usually lies at 18 to 30 inches below the soil surface. The silty-textured surface soils and granular structure provide for easy tillage within a relatively wide range of moisture conditions.

The poorly drained Sharkey soils have more unfavorable physical properties. They occur at elevations ranging from 4 to 7 feet above sea level, and the water table is generally 6 to 16 inches below the surface. Sharkey soils contain from 53 to 63 per cent clay and they are very slowly permeable. The soils are difficult to till because of the clayey-textured surface layers. Closely spaced ditches are required to remove the excess water from the surface layers of most areas of Sharkey soils. Some areas of Sharkey soils at elevations of 3 to 5 feet above sea level are protected from flooding by dikes or levees and drained by pumping when they are planted to cultivated crops. All areas of Commerce silt loam, low phase also occur at low elevations and they are influenced by a usually high water table. Some areas of this soil need protection from flooding and pump drainage when used for cultivated crops.

The somehwat poorly drained Baldwin soils usually occur at elevations of 5 feet or more above sea level. They contain 40 to 53 per cent clay, and the permeability is very slow. The water table commonly lies at 18 to 24 inches below the surface. Tilth is good for the silty-textured Baldwin soils and poor for soils having clayey-textured surface layers. Most areas of Baldwin soils are adequately drained by the gravity flow of water in properly directed furrows.

The somewhat poorly drained to poorly drained Mhoon soils occupy nearly level areas at elevations of 5 to 15 feet above sea level and they are effectively drained by the gravity flow of water in properly directed furrows. The clay contents of the stratified sediments of the Mhoon soils range from 12 to 38 per cent, and the permeability is slow. The usual height of the water table is 14 to 20 inches below the soil surface. The Mhoon soils are easily tilled within a moderately wide range of moisture conditions.

General Properties of the Organic Soils and Clays of the Coastal Marshlands

More than 90 per cent of Terrebonne Parish is made up of the usually wet and frequently flooded coastal marshlands and swamps. This area of wet lands ranges in elevation from sea level or slightly above to as much as 4 or 5 feet above sea level. The soils are formed from alluvial silts and clays carried into the area by streams flowing into and across the marshes and swamps. Most areas of marshlands lying near the shore of the Gulf of Mexico are receiving silty and clayey sediments deposited by waves and tides.

The coastal marshlands lie along the coast of the Gulf of Mexico in a broad, level area. The only observable surface features in most areas of coastal marshlands are the low natural levees associated with the streams that flow into or across the marshlands. These narrow ridges have elevations of a few inches to 1 foot or more above the marshlands. The southern or gulfward parts of these natural levees are at the same elevation as the marshlands, or they are buried beneath the marshlands. A common landscape feature of many marshland areas is a row of small, dead liveoak trees which mark the position of a subsided or buried, narrow natural levee. The coastal marshlands with their luxuriant cover of water-tolerant grasses, sedges, forbs and woody plants occupy an area of slightly more than 670,000 acres, or about 75 per cent of the parish land area. About 73 per cent of the coastal marshlands have a surface mantle of organic materials ranging from 24 inches to more than 84 inches in thickness over clayey sediments. About 27 per cent of the coastal marshlands have clay and mucky clay surface layers over clayey substrata.

Classification of the soil materials of the coastal marshlands is based on the content of organic matter in the surface layers, and on the degree of decomposition or preservation of the organic materials.

Organic materials in which the parts of plants are well preserved and easily identified are classified as peats. Organic materials which are decomposed to the extent that most plant fibers are destroyed are classified as mucks. Colors of the peats and mucks range from dark brown to black. Peats generally have a coarse fibrous structure when dry. The dry mucks commonly have a granular structure. The soil materials classified as peats and mucks have surface layers with organic matter contents of 28 per cent or more. Clayey mucks and silty mucks have surface layers that contain 16 to 27 per cent organic matter. Mucky clays and mucky silty clays contain from 11 to 15 per cent organic matter; and clays have surface layers having an organic matter content of less than 10 per cent.

The assemblages of plants growing in the marshlands differ from place to place because of differences in the degrees of salinity of the areas and to differences in the salt tolerance of the grasses, sedges, forbs and woody plants. The salinity of any area of the coastal marshlands depends mainly on the length of time that salty water or fresh water has had the dominant influence in the area. Salts brought into the coastal marshlands by tides, especially by storm tides of 6 to 10 feet, are removed from some areas by rainfall and by the floodwaters of fresh water streams. Plants will thrive under conditions of favorable salinity, and many plants will survive for a considerable length of time under conditions of unfavorable salinity. Since environmental adjustments of many plants to changes in salinity conditions are slow, it is not uncommon to find plants in the coastal marshlands which are growing in areas that have a salt content outside of the range of their normal salt tolerance. The classification of salinity conditions of the coastal marshlands is based on the salt content of the soil materials. The following salinity classes used in this report are those of Penfound and Hathaway (*9*): Fresh Water Marsh, 0.0 to 0.5 per cent salt; Brackish Marsh, 0.5 to 2.0 per cent salt; Salt Water Marsh, more than 2.0 per cent salt.

Methods of Analysis of Soil Materials and Soil Water of the Coastal Marshlands

The following methods and procedures were used in the analyses of soil materials from 59 profiles and soil water from 53 profiles of Coastal Marshland soils.

Measurements of the pH of soil water and wet soil materials were made in the field with a Hellige-Truog test kit. Laboratory measurements of pH were made on samples of soil water and on soil materials prior to drying, using a glass electrode pH meter and a 1:1 ratio of soil to water as described by Peech et al. (*8*).

Organic matter was calculated by a conversion factor (C x 1.72) from organic carbon determinations as carbon dioxide by the dry combustion method described by Piper (*10*).

Phosphorus and sulphur were determined by the A. O. A. C. (*1*) methods; fusion with sodium carbonate, with phosphorus values measured colorimetrically and sulphur values determined by precipitation as barium sulfate.

The water soluble cations, anions and salts were determined by a modification of the methods of Richards et al. (*11*), using 1 part of soil to 5 parts of water with 12 hours contact and filtered through a Pasteur Chamberlain filter. Aliquots of the extract were used for the analysis of chlorides, potassium, sodium, calcium and magnesium. Chlorine was precipitated by the addition of a silver nitrate solution in the presence of potassium chromate as an indicator. The result of the titration was reported as the percentage of sodium chloride. Potassium and sodium were determined with a Model 52C Perkin-Elmer flame photometer. Calcium and magnesium were determined by Versene titration (*5*). A 50-ml aliquot of the filtrate was heated to dryness at 110° C and ignited to constant weight for the removal of organic matter and for the conversion of bicarbonates to carbonates. This constant weight was used as the weight of total salts. The salts were dissolved in hot, carbon dioxide-free water and carbonates were determined by acid titration using the phenopthalein end-point. Sodium sulfate was calculated as the difference between the total salt content and the sum of sodium chloride plus sodium carbonate. Soil samples from selected horizons of seven soil profiles were prepared for X-ray diffraction analysis and analyzed by Dr. G. W. Kunze, Agronomy Department, Texas A&M University. The samples were prepared and separated into the less than 2 microns clay fraction by the methods of Jackson et al. (*6*). The clay samples were saturated with magnesium and prepared for X-ray diffraction analysis, following the procedures described by Kunze and Templin (*7*). The X-ray diffraction patterns were made with a North American Phillips, high angle goniometer model instrument equipped with a copper target tube. The results of the X-ray diffraction analyses are presented in Table 7.

The following section includes the location, description and chemical data for each of the 59 profiles of soil materials and for samples of soil water from 53 of these sites from the coastal marshlands of Terrebonne Parish. Also included are mineralogical data from the analysis of the <2 microns clay fraction of selected horizons of seven profiles. The dominant plants and their growth height are noted for most sample sites. Since sodium chloride and total salt values were calculated on the air-dry weights of the soil samples, the values obtained are much higher than those found in the soils under normal conditions of moisture. There are many plants which, by frequency of their occurrence, number of individuals, vigor and height of growth, are considered to be typical assemblages in fresh water, brackish and salt water areas. The salt contents of the samples of water from the profile sites are in close agreement with the salt tolerance of the plants found growing at the sample sites.

Each soil profile is located by number on the outline map of the parish on pages 56-57.

The botanical names and the corresponding common names of the dominant plants of the coastal marshlands of Terrebonne Parish are given in Table 6.

Table 6.-Dominant plants of the coastal marshlands of Terrebonne Parish.

Botanical Name	Common Name
GRASSES	
Distichlis spicata	saltgrass, salt marshgrass
Panicum hemitomon	paille fine, maiden cane
Phragmites comminus	common reed, roseau
Spartina alterniflora	oystergrass, seacane
Spartina cynosuroides	big cordgrass, quill cane
Spartina patens	couchgrass, marsh hay
Zizaniopsis miliacea	cutgrass, water millet
FORBS-SEDGES	
Fimbristylis castanea	sandrush
Mariscus jamaicaensis	sawgrass
Scirpus validus	bulrush, softstem bulrush
Scirpus olneyi	three-square grass, triangle sedge
FORBS	
Hibiscus lasiocarpos	rose-mallow
Juncus roemerianus	black rush, needlegrass
Sagittaria lancifolia	delta potato, bull tongue
Salicornia perennis	glasswort
Typha latifolia	cattail
LEGUMES	
Vigna repens	wild cowpea
FERNS	
Osmunda regalis	royal fern
WOODY PLANTS	
Aster elixis	slim aster
Avicennia nitida	black mangrove
Baccharis halimifolia	groundsel bush, marsh elder
Batis maritima	saltwort
Borricha frutescens	sea ox-eye

DESCRIPTIONS OF THE ORGANIC SOILS AND CLAYS OF THE COASTAL MARSHLANDS AND THEIR CHEMICAL CHARACTERISTICS

Soil Profile No. 11 FRESH WATER MARSH CLAY

Sampled near Big Horn Bayou; 1¼ miles from the Lower Atchafalaya River; T. 18 S., R. 12 E., Terrebonne Parish.

0-6"	Dark gray (5Y 4/1)[1] mucky clay with a 4 inch surface mat of coarse fibrous plant materials; pH 6.2.[2]
6-24"	Dark gray (5Y 4/1) clayey muck containing 25 per cent medium and coarse fibrous peat; pH 7.5.
24-84"	Dark gray clay; pH 7.5.
84-156"	Gray (5Y 5/1) clay.

Dominant Vegetation: common reed 12 to 15 feet tall, delta potato 2 to 3 feet tall, and paille fine 3 feet tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm							
Soil[3] Water	5.4				36	208	40	340	115	0.00	0.23	0.25
0-6	4.3	7.9	0.15	140	566	652	103	1780	129	0.44	0.62	1.09
6-24	4.4	37.1	0.42	310	2620	4125	405	6010	473	1.54	1.00	2.65
24-84	4.1								903	1.67	0.58	2.46

[1] Colors by Munsell color notations.

[2] pH readings in the field by Hellige-Truog test kit.

[3] Free soil water sampled from the water-saturated soil.

Soil Profile No. 12 FRESH WATER MARSH CLAYEY MUCK

Sampled near Bayou Penchant, 2.6 miles east of Lake Gasche; southwestern part of T. 17 S., R. 13 E., Terrebonne Parish.

0-14"	Dark gray (10YR 4/1) clayey muck containing 20 per cent coarse fibrous recent plant materials; pH 6.2.
14-36"	Dark gray (10YR 4/1) clayey muck; pH 7.5.
36-132"	Dark gray clay; pH 8.0.

Dominant Vegetation: paille fine 3 feet tall, with delta potato 30 inches tall and common reed 12 to 15 feet tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water					32	259	15	20	86	0.00	0.32	0.34
0-14	5.8	24.5	0.22	623			250	2910	516	0.20	0.73	1.05
14-36	5.2	27.7	0.39	360			199	2240	473	0.43	0.43	0.97
36-132	7.2	4.2							470	0.10	1.32	1.53

Soil Profile No. 13 FRESH WATER MARSH PEATY MUCK

Sampled near Bayou Penchant; 1 mile west of Lake Penchant; northwestern part of T. 19 S., R. 15 E., Terrebonne Parish.

0-4"	Very dark gray (5Y 3/1) muck containing 25 per cent fine fibrous peat; pH 6.0.
4-14"	Black (5Y 2/1) muck matrix containing 40 per cent fine and coarse fibrous peat; pH 6.0.
14-42"	Black finely divided muck containing 25 per cent medium and coarse fibrous peat; pH 6.0.
42-156"	Very dark gray (5Y 3/1) clay with shell fragments; pH 7.8.

Dominant Vegetation: paille fine.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts							
					Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					-----	-----	ppm	-----	-----			
Soil Water					25	177	47	490	190	0.00	0.30	0.35
0-4	5.9	36	0.39	860	1088	2956	1135	16317	1610	0.23	4.69	5.27
4-14	5.6		0.53	844	1064	1168	511	5890	644	0.56	1.54	2.24
14-42	5.5		0.73	866					170	0.23	0.45	0.72
42-156	6.9								175	0.17	0.18	0.39

Soil Profile No. 14   FRESH WATER MARSH PEATY MUCK ✗

Sampled from near St. Paul's Bayou; ½ mile south of the Intracoastal Waterway; northeastern part of T. 18 S., R. 15 E., Terrebonne Parish.

0-6"   Black (10YR 2/1) finely divided muck containing 25 per cent medium and coarse fibrous peat; pH 7.5.

Dominant Vegetation: paille fine 30 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	7.1				13	35	4	48	48	0.01	0.01	0.03
0-6	5.5	36.4	0.35	800	585	51	13	710	735	0.08	0.16	0.41

Soil Profile No. 15 FRESH WATER MARSH PEATY MUCK

Sampled near Bayou Copasaw, 3.1 miles northwest of Lake Penchant; southeastern part of Sec. 19, T. 18 S., R. 15 E., Terrebonne Parish.

0-8"	Black (2.5Y 2/0) finely divided muck containing 20 per cent medium fibrous peat; pH 6.2.
8-16"	Black finely divided muck containing 30 per cent fine and coarse fibrous peat; pH 6.3.
16-36"	Black silty muck matrix containing 20 per cent fine fibrous peat; pH 5.3.
36-108"	Very dark gray (10YR 3/1) clay or silty clay; pH 6.0.
108-152"	Dark gray (10YR 4/1) plastic clay; pH 7.5.

Dominant Vegetation: paille fine, cattail and common reed.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					17	81	23	160	47	0.00	0.12	0.13
0-8	6.2	40.7	0.33	870	768	1127	513	5900	1472	0.04	1.56	1.92
8-16	6.8	47.7	0.77	990	428	1524	390	6440	730	0.17	1.65	1.98
16-36	4.9		1.23	986	1420	1382	537	10600	690	0.71	2.90	3.76
36-108	5.2						90	1457	40	0.46	0.33	0.80
108-152	6.6						90	1463	40	0.27	0.21	0.49

Soil Profile No. 16 FRESH WATER MARSH PEATY MUCK

Sampled near the highway between Bayous St. Jean Charles and Pointe au Chien; ½ mile west of State Highway 968; northwestern part of T. 19 S., R. 20 E., Terrebonne Parish.

0-12"	Dark brown (10YR 4/3) finely divided muck, containing 30 per cent fine and coarse fibrous peat.
12-24"	Black (5Y 2/1) muck containing 20 per cent coarse fibrous peat.
24-48"	Gray (10YR 6/1) plastic clay.

Dominant Vegetation: bulrush and common reed.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					----------	----------	ppm	----------	----------			
Soil Water	6.6				64	171	18	420	170	0.00	0.30	0.34
0-12	6.3	59.8	0.34	368	538	975	144	3830	550	0.69	0.58	1.40
12-24	5.8	62.4	0.36	338	711	619	141	5360	1175	0.25	1.14	1.64
24-48	6.1								125	0.00	0.30	0.33

Soil Profile No. 17 FRESH WATER MARSH MUCKY PEAT

Sampled near Marmande Canal; 2½ miles west of Bayou Du Large and 2 miles east of Lake Theriot; southeastern part of T. 18 S., R. 16 E., Terrebonne Parish.

0-10"	Very dark gray (10YR 3/1) peat; fine and medium fibrous; containing 15 per cent black muck; pH 6.5.
10-20"	Black (10YR 2/1) medium and coarse fibrous peat; pH 6.5.
20-30"	Very dark gray (10YR 3/1) muck, with thin (1 to 2 inch) lenses of gray clay; containing 15 per cent coarse fibrous peat; pH 6.0.
30-72"	Very dark gray (10YR 3/1) mucky clay with thin (1 to 4 inch) lenses of gray (10YR 6/1) clay; pH 7.0.
72-126"	Very dark gray (10YR 3/1) mucky clay with shell fragments; pH 8.0.
126-144"	Black (5Y 2/1) clay with thin (2 to 4 inch) lenses of black muck; pH 8.0.

Dominant Vegetation: common reed 8 to 10 feet tall, with cattail, sawgrass, bulrush and cutgrass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water												0.05
0-10	6.1	40.3	0.72	720	596	558	161	2370	860	0.07	0.53	0.80
10-20	5.2	68.8	2.77	540	3292	2997	346	7780	375	1.97	1.66	3.72
20-30	6.0		0.97	380	52	248	136	2075	85	0.04	0.32	0.38
30-72	6.2				148	241	83	1885	85	0.01	0.31	0.34
72-126	7.5				42	101	96	1940	165	0.00	0.39	0.43
126-144	6.3				108	233	75	2065	125	0.05	0.39	0.47

Soil Profile No. 18 FRESH WATER MARSH MUCKY PEAT

Samples from near Carrion Crow Bayou; 3.7 miles northeast of Carrion Crow Lake; T. 19 S., R. 14 E., Terrebonne Parish.

0-12"	Very dark brown (10YR 2/2) mucky peat; medium and coarse fibrous.
12-24"	Black (10YR 2/1) muck matrix containing 20 per cent coarse fibrous peat.
24-60"	Black (10YR 2/1) mucky clay with thin (2 to 6 inch) lenses of black peat.
60-144"	Gray (5Y 6/1) plastic clay.

Dominant Vegetation: common reed 12 feet tall, cattail 6 feet tall and paille fine 2 feet tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water					23	81	23	210	125	0.00	0.11	0.14
0-12	5.9	51.6	0.71	1200	660	899	316	4170	40	0.66	0.65	1.41
12-24	6.7	36.7	1.05	756	812	1295	259	4660	160	0.86	0.79	1.69
24-60	7.0				1004	939	229	3810	130	0.89	0.63	1.55
60-144	7.5				74	106	112	2005	150	0.01	0.39	0.44

Soil Profile No. 19 FRESH WATER MARSH MUCKY PEAT

Sampled 1 mile south of the east intersection of Bayou Cocodrie and the Intracoastal Waterway; Sec. 58, T. 17 S., R. 15 E., Terrebonne Parish.

0-20" Very dark brown (10YR 2/2) fine and coarse fibrous peat containing 20 per cent black (10YR 2/1) muck; pH 6.5.

Dominant Vegetation: paille fine 48 to 52 inches tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts Ca ppm	Mg ppm	K ppm	Na ppm	CO_3 ppm	Na_2SO_4 %	NaCl %	Total Salts %
Soil Water	6.9				15	20	3	45	45	0.00	0.01	0.02
0-20	5.4	59.5	0.69	680	932	165	12	710	725	0.27	0.16	0.16

Soil Profile No. 20 FRESH WATER MARSH MUCKY PEAT

Sampled along a canal 9 miles southwest of Gibson; south-central part of T. 17 S., R. 14 E., Terrebonne Parish.

0-16"	Very dark brown (10YR 2/2) fine and coarse fibrous peat containing 40 per cent very dark brown muck; pH 6.5.
16-42"	Black (10YR 2/1) fine fibrous mucky peat containing 15 per cent coarse fibrous peat; pH 6.5.
42-54"	Black (10YR 2/1) muck; pH 7.5.
54-84"	Black (10YR 2/1) muck; pH 7.5.
84-132"	Dark gray (10YR 4/1) plastic clay; pH 8.3.

Dominant Vegetation: paille fine 3 feet tall, with common reed 10 to 12 feet tall, and delta potato 3 feet tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth,		Organic	Total	Total	Ca	Mg	K	Na	CO_3	Na_2SO_4	NaCl	Total Salts
Inches	pH	Matter %	Sulphur %	P ppm	ppm					%	%	%
Soil Water									82	0.00	0.18	0.20
0-16	6.0	63.2	0.52	780					126	0.06	0.23	0.32
16-42	6.0	69.4	0.95	800					tr	0.01	0.20	0.21
42-54	6.4	32.2							tr	0.22	0.12	0.34
54-84	6.7	53.3							tr	0.80	0.73	1.53
84-132	7.8	4.6							tr	0.23	0.29	0.52

Soil Profile No. 21 FRESH WATER MARSH MUCKY PEAT

Sampled from near the shore of Lake Theriot; 9 miles southwest of Houma; T. 18 S., R. 16 E., Terrebonne Parish.

0-18"	Black (10YR 2/1) fine fibrous peat containing 30 per cent black muck; pH 6.5.
18-24"	Very dark brown (10YR 2/2) fine and coarse fibrous peat, containing 20 per cent black muck; pH 6.5.
24-36"	Very dark brown (10YR 2/2) and black muck matrix containing 15 per cent coarse fibrous peat; pH 6.5.
36-84"	Very dark gray (10YR 3/1) plastic clay; pH 8.0.
84-108"	Black mucky clay; pH 7.5.
108-132"	Black muck; pH 7.5.
132-156"	Dark gray (10YR 4/1) plastic clay; pH 8.2.

Dominant Vegetation: paille fine.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					------------------	------------------	ppm	------------------	------------------			
Soil Water												
0-18	5.9	70.7	0.06	140	1068	5	17	3520	1161	0.25	0.79	0.02
18-24	6.0	75.9	0.56	364	640	5	129	1480	301	1.43	0.31	1.31
24-36	5.8				296	330	120	1150	387	0.77	0.20	1.81
36-84	6.5				54	71	63	1050	126	0.11	0.16	1.06
84-108	6.6				138	170	104	1935	215	0.28	0.27	0.30
108-132	6.5				1060	550	360	7260	690	0.20	1.82	0.60
132-156	7.7				74	195	171	1975	168	0.10	0.38	2.12

Soil Profile No. 22 **FRESH WATER MARSH MUCKY PEAT** X

Samples collected 1.2 miles northwest of State Highway No. 79, 3 miles west of Montegut; western part of Sec. 28, T. 18 S., R. 18 E., Terrebonne Parish.

0-10"	Very dark brown (10YR 2/2) fine and coarse fibrous peat containing 30 per cent black (10YR 2/1) muck.
10-18"	Gray (10YR 6/1) clay containing 15 per cent fine and coarse fibrous peat.
18-30"	Gray (10YR 6/1) plastic clay.

Dominant Vegetation: paille fine. The area has been drained* and planted to coastal bermudagrass

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil												
Water	5.1				43	40	69	100	65	0.00	0.05	0.07
0-10	5.0	75.1	0.31	276	431	335	153	3950	550	0.04	0.76	0.93
10-18	4.6	13.3	0.20	134	129	76	49	1575	166	0.07	0.29	0.40
18-30	5.7								60	0.06	0.07	0.10

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*Subsided 1.1 feet in 18 months after the field was pump-drained and protected from flooding.

Soil Profile No. 23 FRESH WATER MARSH PEAT

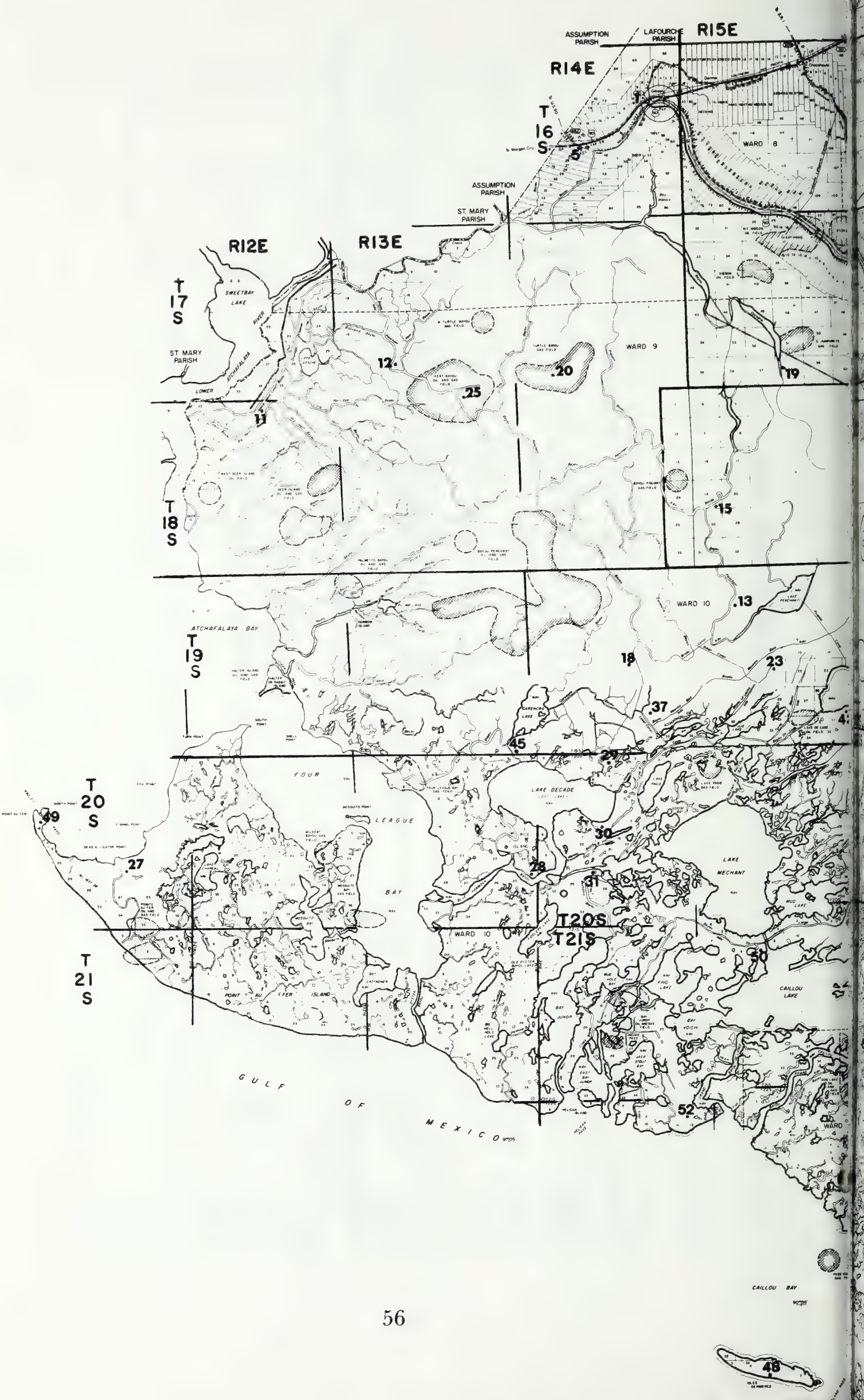
Samples collected 2 miles south of Lake Penchant and 1½ miles east of Bayou Mauvais Bois; south-central part of T. 19 S., R. 15 E., Terrebonne Parish.

0-10"	Very dark brown (10YR 2/2) fine fibrous, felty peat containing 10 per cent muck; pH 6.5.
10-20"	Very dark brown (10YR 2/2) fine and coarse fibrous peat containing 10 per cent black (10YR 2/1) muck; pH 6.0.
20-30"	Black (10YR 2/1) mucky clay with thin (1 to 2 inch) lenses of gray fine sand; pH 6.0.
30-48"	Olive gray (5Y 5/2) very fine sand; pH 7.5.

Dominant Vegetation: bulrush and cattail 7 feet tall.

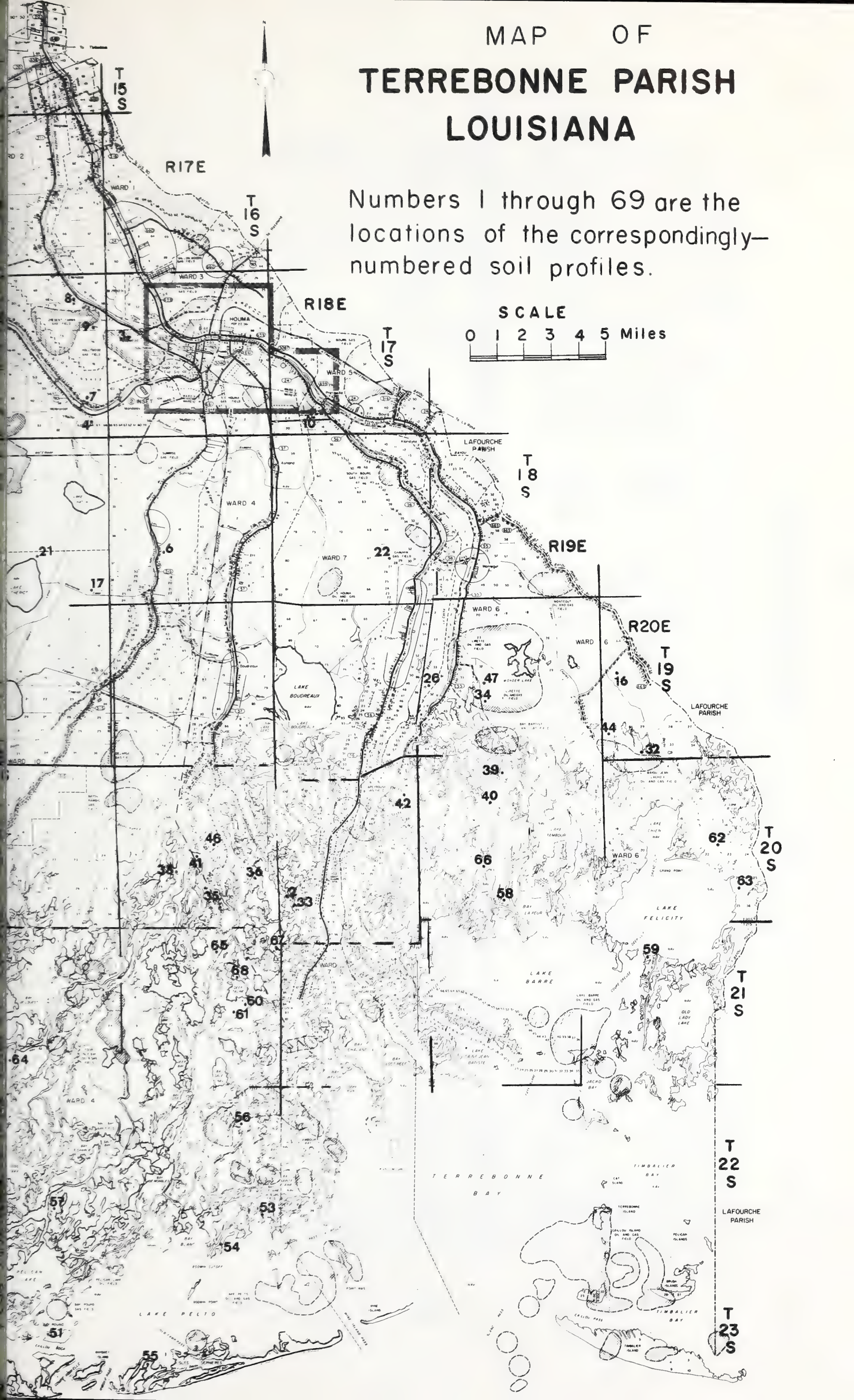
Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil												
Water												0.03
0-10	5.7	53.6	0.91	1050	603	889	150	5490	685	0.16	1.50	1.82
10-20	5.2	46.6	1.94	1020	1581	1447	287	5998	550	0.79	1.76	2.59
20-30	5.8	14.3	0.16	462					80	0.01	0.39	0.43
30-48	7.2								160		0.43	0.49


ASSUMPTION PARISH
LAFOURCHE PARISH
R15E
R14E
T 16 S
WARD 8
ASSUMPTION PARISH
ST. MARY PARISH
R12E
R13E
T 17 S
SWEETBAY LAKE
ATCHAFALAYA RIVER
ST MARY PARISH
LOWER
WARD 9
12
25
20
19
11
T 18 S
15
WARD 10
13
ATCHAFALAYA BAY
T 19 S
18
23
37
45
29
CARENCRO LAKE
FOUR LEAGUE BAY
T 20 S
49
27
LAKE DECADE
30
28
31
LAKE MECHANT
T20S
T21S
WARD 10
T 21 S
POINT AU FER ISLAND
50
CAILLOU LAKE
BAY JUNOP
BAY VOISIN
GULF OF MEXICO
52
WARD 4
CAILLOU BAY
48

MAP OF
TERREBONNE PARISH
LOUISIANA

Numbers 1 through 69 are the locations of the correspondingly-numbered soil profiles.



Soil Profile No. 24 FRESH WATER MARSH PEAT

Sampled 0.2 mile south of Lake De Cade; northern part of Sec. 31, T. 19 S., R. 16 E., Terrebonne Parish.

0-12"	Very dark brown (10YR 2/2) fine and medium fibrous peat containing 10 per cent black (10YR 2/1) muck.
12-24"	Black muck containing 30 per cent coarse fibrous peat.
24-66"	Very dark gray (10YR 3/1) clay.
66-84"	Pale brown (10YR 6/3) fine sand.

Dominant Vegetation: cattail 8 feet tall, delta potato 30 inches tall, rose-mallow 36 inches tall and wild cowpea.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	6.7				43	240	27	240	250	0.00	0.27	0.33
0-12	5.7	55.5	0.67	420	1956	3114	900	20350	1376	0.33	4.35	5.00
12-24	5.7				1724	2621	765	18250	2060	0.99	3.36	4.83
24-66	6.2								290	0.41	0.36	0.84
66-84	7.4								40	0.05	0.11	0.17

Soil Profile No. 25 FRESH WATER MARSH PEAT

Samples collected 100 yards from Bayou Penchant in the southeastern part of T. 17 S., R. 13 E., Terrebonne Parish.

0-16"	Black (5Y 2/1) fine fibrous peat matrix with 20 per cent coarse fibrous parts of present plants; pH 5.5.
16-24"	Dark reddish-brown (5YR2/2) fine and medium fibrous peat containing 25 per cent muck; pH 7.5.
24-36"	Black (5Y 2/1) muck matrix containing 30 per cent fibrous peat; pH 7.5.
36-60"	Very dark brown (10YR 2/2) clayey muck; pH 8.0.
60-96"	Black muck; pH 8.0.
96-144"	Gray (5Y 5/1) clay; pH 8.2.

Dominant Vegetation: paille fine, with cattail, delta potato, rose-mallow and fern.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts							
					Ca	Mg	K	Na	CO_3	Na_2SO_4	NaCl	Total Salts
					------------------ppm------------------					%	%	%
Soil Water							55	650	133	0.17	0.28	0.56
0-16	5.8	58.5	1.08	860			585	12687	1290	0.07	2.71	3.08
16-24	5.6	62.8	1.55	510			180	3500	470	0.20	0.84	1.15
24-36	6.1	55.2					246	2670	540	0.40	1.10	1.63
36-60	6.7	26.5					312	5905	600	0.07	1.91	2.12
60-96	7.0	59.5					124	1724	210	0.24	1.64	1.93
96-144	7.7	4.6					238	2862	640	0.03	0.51	0.69

Soil Profile No. 26 BRACKISH MARSH CLAY

Sampled from a site west of Bayou Barre, 5 miles south of Montegut; in the southeastern part of Sec. 15, T. 19 S., R. 19 E., Terrebonne Parish.

0-16"	Mottled very dark brown (10YR 2/2) and dark gray (10YR 4/1) clay with 5 per cent very dark brown muck; many fine and coarse fibrous parts of couchgrass; pH 7.0.
16-30"	Very dark gray (10YR 3/1) clay with thin (1 to 2 inch) lenses of dark gray (10YR 4/1) fine sand; pH 7.8.
30-42"	Dark gray (10YR 4/1) fine sandy loam with thin lenses of dark gray clay; pH 7.8.

Dominant Vegetation: couchgrass 24 inches tall, with big cordgrass 36 inches tall and saltgrass 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
0-16	6.0	8.1	0.35	530	255	890	425	5680	215	0.08	1.42	1.53
16-30	7.4	2.8	0.24		193	150	201	3360	688	0.04	0.84	0.96
30-42	6.1	2.1										

Soil Profile No. 27 BRACKISH MARSH CLAY

Sampled near Locust Bayou; ½ mile south of Atchafalaya Bay and 3 7/10 miles southeast of Point Au Fer; T. 20 S., R. 11 E., Terrebonne Parish.

0-20"	Very dark grayish brown (10YR 3/2) clay with a two-inch surface mat of coarse fibrous plant materials.
20-48"	Very dark grayish brown mucky silty clay.
48-132"	Dark gray (10YR 4/1) clay.

Dominant Vegetation: saltgrass 2 feet tall, with big cordgrass 3 feet tall and couchgrass 2 feet tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts: Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	CO_3 (ppm)	Na_2SO_4 %	NaCl %	Total Salts %
Soil												
Water	7.2				61	482	150	2150	129	0.02	1.53	1.59
0-20	7.4	8.6	0.17	300	468	411	393	11600	252	0.26	2.34	2.66
20-48	7.9		0.76	124	526	779	472	10500	125	0.92	1.96	2.91
48-132	8.1								170	0.57	2.18	2.79

Soil Profile No. 28 BRACKISH MARSH MUCKY CLAY

Sampled near Blue Hammock Bayou, in the southern part of Rice Island; northeastern part of Sec. 25, T. 20 S., R. 13 E., Terrebonne Parish.

0-10"	Very dark gray (10YR 3/1) mucky clay with a surface mat of coarse fibrous parts of present plants.
10-24"	Very dark gray mucky clay.
24-60"	Very dark gray mucky clay.
60-108"	Dark gray (10YR 4/1) plastic clay.
108-140"	Gray (10YR 6/1) clay with thin (2 to 6 inch) lenses of gray fine sand.

Dominant Vegetation: couchgrass, with three-square grass, sandrush and saltgrass.

Chemical Characteristics

					Water soluble cations anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					92	579	105	1500	172	0.00	1.06	1.10
0-10	6.9	15.1	1.11	430	492	1117	450	8166	476	0.20	2.30	
10-24	7.1		0.92	400	658	1366	470	9175	470	0.26	2.80	
24-60	7.6								425	0.04	2.47	
60-108	7.8								515	0.00	0.90	
108-140	7.8								344	0.00	0.69	

Soil Profile No. 29 BRACKISH MARSH CLAYEY MUCK

Sample site ½ mile northeast of Lake De Cade near Bayou Sambout; central part of Sec. 4, T. 20 S., R. 14 E., Terrebonne Parish.

0-12"	Very dark gray (10YR 3/1) clayey muck containing 20 per cent freshly accumulated organic materials.
12-72"	Very dark gray clayey muck.
72-104"	Gray (10YR 6/1) plastic clay.
104-108"	Gray fine sand.

Dominant Vegetation: couchgrass, with big cordgrass.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts							
					Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					40	208	68	720	135	0.00	0.53	0.56
0-12	6.9	22.2	0.50	520	202	525	330	4800	420	0.08	0.99	1.17
12-72	7.0		2.78	580	192	402	211	4970	334	0.13	1.04	1.25
72-104	8.0								120	0.00	0.40	0.43
104-108	7.8								205	0.00	0.19	0.24

Soil Profile No. 30 **BRACKISH MARSH PEATY MUCK** X

Sample location near Bayou Moreaux Beaux, 1½ miles east of Rice Island; southwestern part of Sec. 16, T. 20 S., R. 14 E., Terrebonne Parish.

0-16"	Very dark gray (10YR 3/1) muck containing 30 per cent medium fibrous peat.
16-36"	Very dark gray (10YR 3/1) muck containing 25 per cent fine fibrous peat.
36-72"	Gray (10YR 6/1) plastic clay.
72-96"	Very dark gray clay.
96-120"	Gray (10YR 6/1) fine sand with shell fragments.

Dominant Vegetation: couchgrass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					65	396	131	1140	162	0.00	0.83	0.87
0-16	6.3	31.6	1.29	516	744	2032	422	7461	850	0.60	4.20	4.90
16-36	7.3		1.61	600	428	1615	800	19180	930	0.18	4.58	4.78
36-72	7.6								340	0.13	1.31	1.52
72-96	7.9								195	0.03	0.91	0.99
96-120	7.9								345	0.00	1.18	1.26

Soil Profile No. 31 BRACKISH MARSH PEATY MUCK

Samples collected from near Blue Hammock Bayou; ¼ mile west of Lake Mechant; southwestern part of Sec. 21, T. 20 S., R. 14 E., Terrebonne Parish.

0-16"	Very dark gray (10YR 3/1) muck matrix containing 20 per cent medium and coarse fibrous peat; pH 8.0.
16-36"	Black (10YR 2/1) oozy muck containing 30 per cent silt and clay; pH 8.2.
36-60"	Dark gray (10YR 4/1) plastic clay; pH 8.2.
60-90"	Dark gray clay with thin (1 to 4 inch) lenses of gray (10YR 6/1) fine sand; pH 8.2.
90-132"	Dark gray (10YR 4/1) clay with shell fragments; pH 8.2.

Dominant Vegetation: couchgrass 18 to 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					86	619	233	2020	80	0.01	1.36	1.39
0-16	6.6	38.0	1.86	628	1024	2905	1260	25950	1040	0.22	6.78	7.24
16-36	7.0	20.1	1.89	440	606	1742	611	14750	600	0.05	4.29	4.48
36-60	7.8				158	495	241	5970	470	0.05	1.11	1.27
60-90	7.8				116	259	204	4130	170	0.12	0.85	1.01
90-132	7.8				138	195	180	4340	165	0.11	0.85	1.00

Soil Profile No. 32 BRACKISH MARSH PEATY MUCK

Sampled from the south side of Lake Pointe Au Chien; 2 miles north of Lake Chien; Sec. 32, T. 19 S., R. 20 E., Terrebonne Parish.

0-18"	Very dark brown (10YR 2/2) muck matrix containing 40 per cent fine and coarse fibrous peat.
18-30"	Black (10YR 2/1) muck containing 20 per cent fine fibrous peat.
30-84"	Gray (10YR 5/1) clay with thin (2 to 4 inch) lenses of very dark gray (10YR 3/1) muck.
84-156"	Gray (10YR 5/1) clay.

Dominant Vegetation: couchgrass, with big cordgrass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	8.1				81	640	173	1730	138	0.01	1.32	1.36
0-18	5.1	38.1	1.80		495	3078	1125	24500	770	0.85	5.29	6.32
18-30	4.7		3.18		732	6807	1890	45500	730	1.73	9.58	11.48
30-84	7.0								500	0.12	1.99	2.25
84-156	8.1								80	0.00	0.35	0.37

Soil Profile No. 33 BRACKISH MARSH PEATY MUCK

Sampled 3 miles north of Cocodrie Station; Sec. 88, T. 20 S., R. 18 E., Terrebonne Parish.

0-6"	Dark brown (10YR 4/3) muck matrix containing 20 per cent coarse and fine fibrous peat; pH 8.2.
6-12"	Dark brown (10YR 4/3) peaty muck with thin (1 inch) lenses of black (10YR 2/1) clay; pH 8.2.
12-36"	Dark gray (10YR 4/1) clay; pH 8.2.
36-44"	Thin strata of dark gray (10YR 4/1) clay and fine sand; pH 8.2.
44-76"	Gray (10YR 6/1) clay; pH 8.2.

Dominant Vegetation: couchgrass, with big cordgrass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K ppm	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
Soil Water					105	518	139	1730	109	0.27	1.20	1.36
0-6	7.4	38.2	1.43	610	1350	3140	1245	29000	840	0.71	7.31	8.22
6-12	7.2	19.8	0.50	270			716	16200	845	0.13	4.03	4.36
12-36	8.1	3.7	0.25	450			307	6175	250	0.05	1.03	1.14
36-44	8.1	1.6					127	4681	335	0.00	0.88	0.97

Soil Profile No. 34 BRACKISH MARSH PEATY MUCK

Sampled from near Bayou Barre; 5 miles south of Montegut; southwestern part of T. 19 S., R. 19 E., Terrebonne Parish.

0-10"	Black (10YR 2/1) muck matrix containing 30 per cent fine and coarse fibrous peat; pH 7.5.
10-30"	Black (10YR 2/1) muck containing 25 per cent finely fibrous peat; pH 7.5.
30-108"	Dark gray (10YR 4/1) clay; pH 7.5.
108-132"	Very dark gray (10YR 3/1) clay with thin (2 to 4 inch) lenses of gray (10YR 6/1) fine sand, pH 7.5.

Dominant Vegetation: couchgrass, with three-square grass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					115	756	186	2260	125	0.01	1.13	1.17
0-10	6.5	38.9	1.94	704	2096	4546	1650	32200	1180	0.23	8.71	9.25
10-30	6.6	46.3	2.45	490	2250	5062	4860	71500	645	1.01	9.41	10.57
30-108	6.6	6.3							215	0.00	1.64	1.69
108-132	6.7	2.9							169	0.00	0.61	0.65

Soil Profile No. 35 BRACKISH MARSH PEATY MUCK

Sampled near Wax Bayou; 6 miles south of Dulac and 5 miles northwest of Cocodrie Station; western part of Sec. 27, T. 20 S., R. 17 E., Terrebonne Parish.

0-12"	Very dark brown (10YR 2/2) muck matrix containing 25 per cent fine and medium fibrous peat.
12-20"	Very dark brown (10YR 2/2) peaty muck.
20-36"	Gray (10YR 5/1) clay.

Dominant Vegetation: couchgrass 24 to 36 inches tall, with big cordgrass 48 inches tall.

Chemical Characteristics

					Water soluble cations anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm							
Soil Water	8.2				329	675	143	2050	160	0.00	1.45	1.47
0-12	6.7	40.1	0.79	220	2094	4058	1620	39300	2100	0.63	8.09	9.21
12-20	6.8	29.8	0.59	40	1938	3774	1440	38900	1495	0.41	8.38	9.14
20-36	7.1		0.06	160	170	193	69	2615	160	0.14	1.00	1.18

Soil Profile No. 36 BRACKISH MARSH PEATY MUCK

Sampled from the shore of lake between Grassy Bayou and Bayou Sale; 6 miles southeast of Dulac; Sec. 25, T. 20 S., R. 17 E., Terrebonne Parish.

0-10"	Black (10YR 2/1) muck matrix containing 20 per cent dark reddish-brown (5YR 3/2) finely fibrous peat.
10-36"	Black peaty muck.
36-72"	Gray (10YR 6/1) clay.
72-84"	Dark brown (10YR 4/3) clayey muck.
84-120"	Gray (10YR 6/1) clay.
120-156"	Gray (10YR 6/1) fine sand.

Dominant Vegetation: oystergrass 36 to 60 inches tall, saltgrass 30 inches tall, big cordgrass, and groundsel bush.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K ppm	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
Soil Water	7.3				129	848	225	2430	118	0.06	1.80	1.92
0-10	4.9	41.5	1.09	228	2008	4048	1057	23350	1140	2.64	4.68	7.58
10-36	5.6				2120	5506	1830	47000	1540	1.55	10.32	12.23
36-72	7.9								120	0.03	1.66	1.73
72-84	6.6								325	0.10	3.55	3.73
84-120	7.7								115	0.03	0.92	0.98

Soil Profile No. 37 **BRACKISH MARSH PEATY MUCK**

Sampled from near Love Canal, between Carrion Crow Bayou and Bayou Mauvais Bois; 3/8 mile northwest of Lake Mechant ; southeastern part of T. 19 S., R. 14 E., Terrebonne Parish.

0-10"	Very dark brown (10YR 2/2) peaty muck.
10-24"	Black (10YR 2/1) muck matrix containing 20 per cent medium and fine fibrous peat.
24-36"	Black mucky clay.
36-108"	Dark gray (10YR 4/1) clay.
108-132"	Gray (10YR 6/1) fine sand.

Dominant Vegetation: couchgrass and three-square grass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					60	375	103	1060	214	0.00	0.76	0.81
0-10	6.0	46.4	1.74	666	768	1000	594	12400	1140	0.13	2.87	3.26
10-24	6.6		1.74	660	832	1498	370	7927	1090	0.14	4.37	4.76
24-36	7.2								375	0.80	0.93	1.82
36-108	7.3								205	0.02	0.41	0.48
108-132	7.2								85	0.23	0.20	0.45

Soil Profile No. 38 BRACKISH MARSH PEATY MUCK

Sampled along the south shore of Felix Lake; 5½ miles southwest of Dulac; southwestern part of Sec. 21, T. 20 S., R. 17 E., Terrebonne Parish.

0-6"	Very dark brown (10YR 2/2) muck matrix containing 20 per cent medium and coarse fibrous peat.
6-18"	Black (10YR 2/1) muck matrix containing 40 per cent coarse fibrous peat.

Dominant Vegetation: couchgrass 36 inches tall, with sand rush 40 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm							
Soil Water	6.6				84	538	376	3910	145	0.01	1.14	1.19
0-18	5.1	49.1	2.03	812	1908	1921	46	24800	2275	0.39	7.42	8.54

Soil Profile No. 39 BRACKISH MARSH PEATY MUCK

Sampled near Bayou Barre, 1½ miles northwest of Lake Tambour; T. 20 S., R. 19 E., Terrebonne Parish.

0-12"	Black (5Y 2/1) muck matrix containing 20 per cent very dark brown (10YR 2/2) medium and coarse fibrous peat; pH 8.0.
12-60"	Very dark brown (10YR 2/2) peaty muck; pH 8.0.
60-108"	Very dark gray (5Y 3/1) clay with thin (2 to 4 inch) lenses of gray (5Y 6/1) fine sand; pH 8.2.
108-132"	Very dark gray (5Y 3/1) clay with thin lenses of gray (5Y 6/1) fine sand; pH 8.2.

Dominant Vegetation: oystergrass 24 inches tall, with black rush.

Chemical Characteristics

					Water soluble cations anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					295	741	206	2810	164	0.01	1.93	1.98
0-12	7.3	28.5	1.14	388	1152	3520	1340	27106	510	0.03	8.35	8.50
12-60	7.2	34.8	1.28	320			2430	56700	1175	0.33	13.93	14.53
60-108	7.5	6.8					701	16525	680	0.04	3.14	3.34
108-132	7.9	3.8							290	0.15	3.21	3.43

Soil Profile No. 40 BRACKISH MARSH PEATY MUCK

Sample site 1½ miles west of Lake Tambour; T. 20 S., R. 19 E., Terrebonne Parish.

0-6"	Black (5Y 2/1) muck matrix containing 20 per cent coarse fibrous plant parts.
6-24"	Very dark brown (10YR 2/2) muck matrix containing 35 per cent medium and coarse fibrous peat; pH 8.0.

Dominant Vegetation: black rush 30 inches tall, with oystergrass 18 to 24 inches tall. Saltwort and glasswort near bayou.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	6.7				112	777	125	5900	140	0.03	1.65	1.71
0-24	5.0	31.5	1.92	410	1714	2641	88	36025	3090	0.89	10.22	11.73

Soil Profile No. 41 BRACKISH MARSH MUCKY PEAT

Sampled 5 miles south of Dulac, between Plat and Wax bayous; eastern part of Sec. 21, T.20 S., R.17 E., Terrebonne Parish.

0-14" Very dark brown (10YR 2/2) medium and coarse fibrous peat containing 15 per cent black (10YR 2/1) muck.

Dominant Vegetation: couchgrass 36 inches tall, with aster 24 inches tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts							
					Ca	Mg	K	Na	CO_3	Na_2SO_4	NaCl	Total Salts
					ppm	ppm	ppm	ppm	ppm	%	%	%
Soil Water	7.3				69	441	325	3605	135	0.01	0.97	1.02
0-14	5.4	46.1	1.96	724	1418	1649	58	21500	2750	0.65	5.66	7.05

Soil Profile No. 42 BRACKISH MARSH MUCKY PEAT

Sampled 5 miles west of Lake Tambour and 6½ miles southwest of Wonder Lake; western part of Sec. 56, T.20 S., R.18 E., Terrebonne Parish.

0-12"	Black (10YR 2/1) peat matrix containing 20 per cent black muck.
12-24"	Very dark brown (10YR 2/2) muck containing 20 per cent medium and coarse fibrous peat.
24-40"	Gray (10YR 6/1) clay.

Dominant Vegetation: oystergrass 24 to 30 inches tall, with couchgrass 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					----------	----------	ppm	----------	----------			
Soil Water	7.0				162	584	101	1680	225	0.02	1.28	1.36
0-12	5.0	49	1.12	280	2241	4287	1365	34000	1110	1.84	7.48	9.58
12-24	6.6				2139	2684	607	17250	200	1.80	3.15	5.00
24-40	6.8								245	0.18	0.99	1.23

Soil Profile No. 43 BRACKISH MARSH MUCKY PEAT

Sampled 0.2 mile from the southwestern shore of Lake De Cade; southwestern part of Sec. 25, T. 19 S., R. 15 E., Terrebonne Parish.

0-12"	Very dark brown (10YR 2/2) fine and medium fibrous peat containing 40 per cent muck.
12-24"	Very dark brown peaty muck.
24-48"	Very dark gray (10YR 3/1) clay.
48-72"	Dark gray (10YR 4/1) clay with lenses of gray (10YR 6/1) fine sand.
72-84"	Gray (10YR 6/1) fine sand.

Dominant Vegetation: couchgrass 30 inches tall, with cattail 7 feet tall, sawgrass 36 inches tall, and three-square grass 48 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	6.7				47	238	61	700	86	0	0.51	0.53
0-12	5.1	50.0	0.84	328	2305	4024	937	25750	1410	1.40	6.03	7.73
12-24	5.1				2327	3667	892	20050	2064	1.77	3.93	6.18
24-48	5.3								725	0.76	0.80	1.73
48-72	6.7								80	0.04	0.30	0.36
72-84	7.0								85	0.07	0.16	0.25

Soil Profile No. 44 BRACKISH MARSH MUCK

Samples from near Cut-Off Canal, 1 mile south of the end of the road at Pointe Au Chien; southwestern part of T.19 S., R.20 E., Terrebonne Parish.

0-8"	Black (10YR 2/1) muck containing 20 per cent coarse fibrous recent plant parts.
8-30"	Very dark brown (10YR 2/2) muck containing 30 per cent fine fibrous peat.
30-132"	Gray (10YR 6/1) plastic clay.
132-156"	Gray fine sand with thin (2 to 3 inch) lenses of gray clay.

Dominant Vegetation: couchgrass 24 to 30 inches tall, with oystergrass 60 to 72 inches tall, aster and saltgrass.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water	7.8				91	645	188	1830	86	0.01	1.40	1.41
0-8	5.5	31.4			1086	3169	1380	28500	940	0.43	6.83	7.48
8-30	2.6				1810	2051	900	45200	195	6.77	7.07	13.89
30-132	6.9				296	993	502	10750	415	0.01	2.18	2.30
132-156	8.1				86	81	82	2600	165	0.00	0.47	0.51

Soil Profile No. 45 BRACKISH MARSH MUCK

Sampled near Crochet Canal; on the north shore of Lake Decade; southeastern part of T.19 S., R.13 E., Terrebonne Parish.

0-14"	Very dark gray (10YR 3/1) muck with a mat of coarse fibrous plant materials on the surface; pH 7.8.
14-24"	Very dark brown (10YR 2/2) muck; pH 7.8.
24-30"	Very dark gray (10YR 3/1) muck; pH 7.8.
30-42"	Very dark gray mucky clay; pH 8.2.
42-132"	Very dark gray clay; pH 8.2.

Dominant Vegetation: three-square, with saltgrass and couchgrass.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water												
0-14	7.1	32.1							60	0.01	0.52	0.56
14-24	7.1								1080	0.06	3.09	3.39
24-30	7.2								1120	0.01	4.50	4.68
30-42	7.4								210	0.00	1.78	1.83
42-132	7.9								252	0.01	0.90	0.97
									84	0.01	0.61	0.61

Soil Profile No. 46 BRACKISH MARSH PEAT

Sampled near Deep Bayou which lies between Four Point and Plat Bayous; 4 miles south of Dulac; southwestern part of Sec. 15, T.20 S., R.17 E., Terrebonne Parish.

0-24"	Very dark brown (10YR 2/2) fine fibrous peat containing 15 per cent coarse fibrous plant materials.
24-48"	Dark gray (10YR 4/1) clay.

Dominant Vegetation: couchgrass 36 inches tall, big cordgrass 36 to 48 inches tall and sand rush.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					------------	------------	ppm	------------	------------			
Soil Water	8.3				208	563	124	1830	122	0	1.28	1.31
0-24	6.9	58.2	0.98	240	1357	3316	1365	40500	1895	0.48	7.88	8.78
24-48	8.2				129	317	79	3015	80	0.13	1.14	1.33

Soil Profile No. 47 BRACKISH MARSH PEAT

Sample collected near Bayou Barre; 5 miles south of Montegut; T.19 S., R.19 E., Terrebonne Parish.

0-24" Very dark brown (10YR 2/2) medium and coarse fibrous peat; pH 7.5.

Dominant Vegetation: couchgrass 30 inches tall, with three-square grass 30 inches tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					----------	ppm	----------	----------	----------			
Soil Water	6.8				93	508	398	4410	138	0.03	1.15	1.23
0-24	4.0	61.9	3.11	606	3920	3060	44	28500	1630	3.74	8.10	12.22

Soil Profile No. 48 SALT WATER MARSH FINE SAND

Samples collected from the central part of West Isles Derniere; 12 miles south of the south shore of Caillou Lake; T.23 S., R.15 E., Terrebonne Parish.

0-6"	Light brownish-gray (10YR 6/2) fine sand with thin lenses of dark gray (10YR 4/1) silty clay loam and clay.
6-20"	Dark gray (10YR 4/1) silty clay and clay.
20-30"	Dark gray silt loam with 1 to 2 inch lenses of very fine sandy loam and peat.
30-42"	Gray (10YR 5/1) very fine sand with thin lenses of gray silt loam and clay.

Dominant Vegetation: black mangrove 24 inches tall, with sea ox-eye 18 to 24 inches tall and saltwort 12 to 18 inches tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts Ca	 Mg	 K	 Na	 CO_3	 Na_2SO_4 %	 NaCl %	 Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil												
Water	7.3				193	1508	473	4370		0	3.33	3.56
0-6	7.0	2.1	.81	190	189	523	482	5799	410	0.10	1.58	1.78
6-20	7.3				364	774	622	12275	385	0.31	2.47	2.87
20-30	6.0								425	0.32	3.00	3.42
30-42	6.3								260	0.29	1.55	1.92

Note: Water from the Gulf of Mexico south of West Isles Derniere = 2.74% NaCl.

Soil Profile No. 49 SALT WATER MARSH SILTY CLAY

Sampled and described from the island east of Raguet Pass; ½ mile south of North Point, Point Au Fer; T.20 S., R.11 E., Terrebonne Parish.

0-14"	Brown (10YR 5/3) silty clay and clay with many coarse roots of black mangrove.
14-24"	Brown (10YR 5/3) mottled gray (10YR 5/1) silty clay.
24-32"	Gray (10YR 5/1) mottled reddish-brown (5YR 5/4) silty clay and clay.

Dominant Vegetation: black mangrove 36 inches tall, with saltwort 24 to 30 inches tall and glasswort 14 to 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
Soil Water	7.0				271	1986	450	5340	185	0.07	4.12	4.26
0-14	7.5	4.1	0.04	276	204	398	405	10375	205	0.01	2.13	2.19
14-24	7.3		0.01	256	225	297	413	12100	380	0.12	2.51	2.72
24-32	7.5								420	0.10	2.76	2.96

Soil Profile No. 50 SALT WATER MARSH CLAY

Sample site near Grand Pass, on the shore of Caillou Lake; T.21 S., R.15 E., Terrebonne Parish.

0-16"	Very dark gray (10YR 3/1) clay with a surface mat of coarse fibrous parts of oystergrass; pH 8.0.
16-36"	Very dark gray (10YR 3/1) mucky clay; pH 8.2.
36-132"	Very dark gray mucky clay; pH 8.2.
132-144"	Gray (5Y 5/1) clay with thin sand lenses; pH 8.2.

Dominant Vegetation: oystergrass

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					116	965	236	3180	162	0.01	2.13	2.19
0-16	7.6	5.0	0.87	292	667	2404	442	12775	415	0.02	3.18	3.30
16-36	7.7	12.4	0.80	310	556	1803	697	13057	325	0.16	3.75	3.99
36-132	7.7	14.1							315	0.01	6.53	6.62
132-144	7.3	3.1							0	0.02	1.35	1.37

Soil Profile No. 51 SALT WATER MARSH CLAY

Sampled from the island between Bay Round and Caillou Boca; 5 miles southwest of Bodwin Point; T.23 S., R.16 E., Terrebonne Parish.

0-5"	Very dark grayish brown (10YR 3/2) clay.
5-16"	Very dark gray (10YR 3/1) clay.
16-120"	Very dark gray clay.
120-156"	Very dark gray clay with thin (2 to 4 inch) lenses of gray (10YR 5/1) fine sand.

Dominant Vegetation: black mangrove 36 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil												
Water	7.9				319	2565	612	5750	192	0.02	4.96	5.27
0-5	7.0	6.9	0.11	220	623	1612	791	18550	505	0.01	4.58	4.71
5-16	7.3	7.3	0.26	140	679	2265	1335	26700	530	0.52	5.93	6.58
16-120	7.9				620	1800	1230	25550	1030	0.41	3.94	4.59
120-156	7.7				376	391	525	10025	425	0.12	2.00	2.22

Soil Profile No. 52 SALT WATER MARSH SILTY CLAY LOAM

Samples collected 0.4 mile inland from Caillou Bay and 1 mile west of the mouth of Grand Bayou Du Large; T.22 S., R.14 E., Terrebonne Parish.

0-18"	Dark gray (10YR 4/1) silty clay loam containing 5 per cent coarse fibrous plant parts.
18-60"	Black (10YR 2/1) silty clay loam with thin (2 to 8 inch) lenses of black clay; contains 5 per cent coarse fibrous peat.
60-84"	Dark gray (10YR 4/1) very fine sand.

Dominant Vegetation: oystergrass 12 to 18 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					----------	----------	ppm	----------	----------			
0-18	6.9	8.3	0.05	186	516	1468	675	15350	250	0.46	3.59	4.11
18-60	7.6		0.46	166	696	1569	532	18350	330	0.68	3.83	4.59
60-84	7.7				146	104	246	4840	200	0.13	1.12	1.30

Soil Profile No. 53 SALT WATER MARSH CLAY

Sampled from a small island in Bay Sainte Elaine; 1½ miles southwest of St. Elaine Pass; T.22 S., R.17 E., Terrebonne Parish.

0-8"	Very dark gray (10YR 3/1) plastic clay, containing 10 per cent coarse and fine fibrous plant remains; pH 7.5.
8-16"	Very dark gray plastic clay; pH 8.0.
16-30"	Black (5Y 2/1) muck containing 15 per cent very dark brown (10YR 2/2) fine and coarse fibrous peat; pH 8.0.
30-48"	Very dark gray (10YR 3/1) clay; pH 8.0.
48-72"	Black (5Y 2/1) muck; pH 8.0.
72-132"	Very dark gray (10YR 3/1) clay; pH 8.2.
132-156"	Dark gray (10YR 4/1) very fine sand; pH 8.2.

Dominant Vegetation: black mangrove 18 to 36 inches tall, with oystergrass and saltwort 18 to 24 inches tall, and glasswort 12 to 14 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					206	1686	413	4440	88	0.01	3.26	3.29
0-8	6.6	10.2	0.14	200	210	944	525	13700	535	0.16	2.95	3.24
8-16	7.0	7.7	0.38	130	446	1498	1027	20600	545	0.41	3.94	4.48
16-30	8.1								640	0.37	9.28	9.80
30-48	8.1								515	0.32	5.75	6.19
48-72	7.8								550	0.30	7.77	8.20
72-132	7.9								690	0.12	4.64	4.92
132-156	8.0								160	0.01	0.93	0.98

Soil Profile No. 54 SALT WATER MARSH MUCKY CLAY

Sampled from an island near the north shore of Lake Pelto; 2 miles northeast of Bodwin Point; T.22 S., R.17 E., Terrebonne Parish.

0-6"	Very dark gray (5Y 3/1) mucky clay containing 5 per cent medium and coarse fibrous parts of black mangrove plants; pH 7.8.
6-24"	Very dark gray clayey muck containing 5 per cent coarse fibrous plant materials; pH 8.0.
24-42"	Very dark gray (5Y 3/1) plastic clay; pH 8.2.
42-60"	Black (10YR 2/1) and very dark brown (10YR 2/2) muck containing 10 per cent peat; pH 8.3.
60-120"	Dark gray (5Y 4/1) clay ; pH 8.3.

Dominant Vegetation: black mangrove 12 to 30 inches tall, with saltwort and glasswort 12 to 14 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					----------------	----------------	ppm	----------------	----------------			
0-6	7.0	11.9	0.14	160	368	1107	656	15500	460	0.16	3.43	3.70
6-24	7.5	16.5	0.43	120	924	2207	1305	30250	475	0.47	6.53	7.11
24-42	8.0								559	0.23	5.32	5.68
42-60	7.9								690	0.07	12.72	13.05
60-96	8.1								680	0.12	4.08	4.36
96-120	8.7								285	0.00	0.46	0.53

Soil Profile No. 55 SALT WATER MARSH MUCKY CLAY

Sampled from the northern side of Isles Dernieres; 3 miles southwest of Bodwin Point Island and 1½ miles east of Whiskey Pass; T.23 S., R.16 E., Terrebonne Parish.

0-10"	Very dark gray (5Y 3/1) mucky clay conatining 10 per cent coarse fibrous parts of black mangrove plants.
10-28"	Stratified very dark gray clay and gray (10YR 5/1) very fine sand.
28-48"	Very dark gray mucky clay.
48-72"	Dark gray (5Y 4/1) clay with thin (2 to 4 inch) lenses of gray (10YR 6/1) very fine sand.
72-108"	Stratified dark gray silt and clay, with gray (5Y 6/1) very fine sand.
108-120"	Gray (5Y 6/1) sand with lenses of silt and clay.

Dominant Vegetation: black mangrove 18 to 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					-------	-------	ppm	-------	-------			
Soil Water					207	1783	450	2580	344	0.01	3.61	3.69
0-10	7.1	12.6	0.41	140	598	2108	1035	23800	760	0.63	4.94	5.75
10-28	7.7	7.2	0.30	70	376	1569	873	16375	385	0.48	3.63	4.20
28-48	7.9				616	2237	1042	24550	475	0.34	5.55	6.00
48-72	7.8				364	1104	547	12700	120	0.49	2.46	2.98
72-108	7.8				128	304	229	5120	285	0.04	1.11	1.22
108-120	7.9				148	546	345	8150	425	0.15	1.93	2.18

Soil Profile No. 56 SALT WATER MARSH MUCKY CLAY

Sampled north of Crooked Bayou; 1 mile southeast of Bay Touch-Me-Not; northeastern part of T.22 S., R.17 E., Terrebonne Parish.

0-18"	Dark gray (10YR 4/1) mucky clay; pH 8.2.
18-48"	Very dark brown (10YR 2/2) peaty muck; pH 8.2.
48-60"	Dark reddish-brown (5YR 3/2) muck containing 15 per cent coarse fibrous peat; pH 8.2.
60-120"	Gray (5Y 5/1) plastic clay; pH 8.2.
120-132"	Gray clay with lenses of gray (10YR 6/1) fine sand; pH 8.2.

Dominant Vegetation: oystergrass with saltwort and sea ox-eye.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water					163	1046	251	3180	129	0.01	2.16	2.21
0-18	6.8	13.2	0.92	400					255	0.15	3.83	4.04
18-48	6.5	26.9	1.48	405					200	0.13	10.33	19.47
48-60	5.6	45.6							470	0.06	13.09	13.37
60-120	7.9	3.6							205	0.18	2.24	2.47

Soil Profile No. 57 SALT WATER MARSH MUCKY CLAY

Sample site near Colyell Bayou; 2 miles north of Pelican Lake; T.22 S., R.16 E., Terrebonne Parish.

0-6"	Very dark brown (10YR 2/2) clay with fine and coarse fibrous parts of oystergrass; pH 7.5.
6-9"	Very dark brown (10YR 2/2) clay stratified with gray (10YR 5/1) fine sand; pH 7.5.
9-36"	Very dark brown (10YR 2/2) coarse fibrous peat; pH 8.0.
36-48"	Black (5Y 2/1) muck; pH 8.0.
48-132"	Dark gray (5Y 4/1) clay with thin (2 to 6 inch) strata of fine sand; pH 8.0.

Dominant Vegetation: oystergrass

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
0-6	5.6	13.3	0.79	515	941	3200	1460	19257	1490	0.28	5.83	5.96
6-9	4.6		0.74	360	567	1765	727	12000	258	0.50	3.06	3.62
9-36	5.7		1.18	334					765	0.21	11.28	11.67
36-48	5.8								605	0.16	9.52	9.82
48-132	7.3								255	0.09	1.58	1.74

Soil Profile No. 58 SALT WATER MARSH MUCKY CLAY

Sample site near Flat Bayou north of Lake Barre; ½ mile west of Bay La Peur; southern part of T.20 S., R.19 E., Terrebonne Parish.

0-4"	Very dark gray (5Y 3/1) mucky clay containing 5 per cent medium and coarse fibrous parts of present vegetation; pH 7.5.
4-24"	Very dark gray (5Y 3/1) mucky clay containing 10 per cent coarse and fine fibrous peat; pH 7.5.
24-60"	Black (5Y 2/1) and dark reddish-brown (5YR 3/4) fine fibrous peat containing 25 per cent muck; pH 7.5.
60-72"	Dark gray (5Y 4/1) mucky clay ooze, including a 4 inch layer of dark reddish-brown (5YR 3/4) peat; pH 8.0.
72-140"	Dark gray (5Y 4/1) clay with thin (2 to 6 inch) lenses of dark gray fine sand; pH 8.0.

Dominant Vegetation: oystergrass 12 to 28 inches tall, with black rush 30 to 36 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm	ppm	ppm	ppm	ppm			
0-4	6.6	13.6	0.74	584								5.58
4-24	6.4	12.8	1.34									5.55

Soil Profile No. 59 SALT WATER MARSH CLAYEY MUCK

Sampled near Pass Coupe Creuse; between Lake Felicity and Lake Barre; T.21 S., R.20 E., Terrebonne Parish.

0-6"	Dark olive gray (5Y 3/2) clayey muck containing 10 per cent coarse fibrous parts of oystergrass.
6-14"	Very dark gray (5Y 3/1) mucky clay containing 20 per cent coarse fibrous parts of oystergrass.
14-36"	Very dark brown (10YR 2/2) fine fibrous peat.
36-72"	Black (5Y 2/1) peaty muck.
72-96"	Very dark brown (10YR 2/2) mucky clay.
96-120"	Dark gray (5Y 4/1) clay.
120-156"	Very dark gray (5Y 3/1) clay with thin (2 to 6 inch) lenses of gray (5Y 6/1) fine sand.

Dominant Vegetation: sparse cover of oystergrass 12 to 18 inches tall; many areas of mud flats with no vegetation.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					--------	--------	ppm	--------	--------			
Soil Water					116	909	304	2760	170	0.19	2.01	2.33
0-6	4.7	17.0	0.52	154	660	1198	1095	21600	815	0.32	4.28	5.79
6-14	3.3				1450	2402	915	21300	375	0.57	4.35	6.01
14-36	6.0								985	0.18	11.42	11.83
36-72	5.1								905	0.97	8.26	9.44
72-96	6.9								430	0.63	5.20	5.93
96-120	7.6								215	0.16	0.84	1.05
120-156	7.7								43	0.12	0.67	0.80

Soil Profile No. 60 SALT WATER MARSH CLAYEY MUCK

Sample site near a bayou, 2 miles west of Cocodrie Station; T.21 S., R.17 E., Terrebonne Parish.

0-12" Black (5Y 2/1) clayey muck containing 15 per cent coarse fibrous parts of the present vegetation; pH 6.5.

Dominant Vegetation: saltgrass 14 to 18 inches tall, with oystergrass 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	7.4				233	1427	385	11200	152	0.10	3.05	3.22
0-12	4.2	17.1	1.32	584	1342	1856	440	27500	2725	0.74	7.12	8.50

Soil Profile No. 61 SALT WATER MARSH CLAYEY MUCK

Sample site near soil profile No. 60 except 150 feet from the bayou; 2 miles west of Cocodrie Station; T.21 S., R.17 E., Terrebonne Parish.

0-18" Very dark brown (10YR 2/2) clayey muck containing coarse fibrous parts of oystergrass; pH 8.2.

Dominant Vegetation: oystergrass 18 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	8.2				146	1163	954	8975	155	0.04	2.60	2.69
0-18	5.2	19.6	1.81	524	1572	1945	720	27300	2190	1.35	7.36	9.22

Soil Profile No. 62 SALT WATER MARSH CLAYEY MUCK

Sample site between Lake Felicity and Bayou Jean Lacroix; Sec. 23, T.20 S., R20 E., Terrebonne Parish.

0-12"	Black (5Y 2/1) clayey muck with a surface mat of coarse fibrous plant materials.
12-60"	Black (5Y 2/1) muck matrix containing 20 per cent medium and fine fibrous peat.
60-96"	Gray (5Y 6/1) clay.
96-132"	Gray (5Y 6/1) fine sand.

Dominant Vegetation: oystergrass 24 to 30 inches tall, with saltgrass 18 to 24 inches tall. Snails on the vegetation at 16 inches above the soil surface.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
0-12	6.0	22.8	1.34		521	3500	1500	34700	1075	0.07	7.94	8.26
12-60	5.2		3.48		560	5715	2520	50400	1625	0.99	10.80	12.17
60-96	7.6				129	375	270	5800	260	0.23	1.10	1.39
96-132	8.6				68	55	141	2155	125	0.03	0.34	0.40

Soil Profile No. 63 SALT WATER MARSH CLAYEY MUCK

Sampled 100 feet from the northeastern shore of Lake Felicity; ½ mile southeast of the mouth of Bayou Jean Lacroix; southeastern part of Sec. 26, T.20 S., R.20 E., Terrebonne Parish.

0-10"	Black (5Y 2/1) clayey muck with the surface covered with a mat of coarse fibrous parts of oystergrass; pH 7.5.
10-24"	Black (5Y 2/1) mucky clay containing 20 per cent coarse fibrous peat; pH 8.0.
24-42"	Black clay stratified with black muck; pH 8.2.
42-84"	Gray (5Y 5/1) clay; pH 8.3.
84-120"	Gray fine sand; pH 8.3.

Dominant Vegetation: oystergrass, with black rush and saltwort.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water												2.90*
0-10	5.6	23.6	0.38	200	932	2448	920	11537	770	0.23	5.00	6.14
10-24	4.8				2215	6289	2100	55800	1480	3.65	11.31	15.32
24-42	6.0								1450	2.10	7.57	10.01
42-84	7.2								515	0.92	4.70	5.74
84-120	7.5								120	0.06	0.40	0.49

*Total Salts value by Wheatstone Bridge.

Soil Profile No. 64 SALT WATER MARSH CLAYEY MUCK

Sampled 100 feet east of the eastern shore of Hackberry Lake; in southeastern part of Sec. 29, T.21 S., R.16 E., Terrebonne Parish.

0-12"	Very dark gray (5YR 3/1) clayey muck containing 10 per cent coarse fibrous peat; pH 8.0.
12-60"	Dark grayish-brown (10YR 4/2) mucky clay containing 15 per cent coarse fibrous peat; pH 8.0.

Dominant Vegetation: oystergrass 12 inches tall, with black rush 18 to 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water												2.40
0-12	6.7	25.2	3.97	542	862	5750	2100	47100	1415	0.05	10.16	10.45
12-60	7.1		1.49	540	1228	3851	1920	47700	1460	0.16	10.48	10.98

Soil Profile No. 65 SALT WATER MARSH MUCK

Sampled 8 miles south of Dulac; between Bayou Sale and Four Point Bayou; Sec. 3, T.21 S., R.17 E., Terrebonne Parish.

0-8"	Black (5Y 2/1) muck.
8-14"	Very dark brown (10YR 2/2) fine and coarse fibrous peat.

Dominant Vegetation: couchgrass and big cordgrass 36 inches tall, glasswort and saltgrass 24 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO$_3$	Na$_2$SO$_4$ %	NaCl %	Total Salts %
					ppm							
Soil Water	6.3				158	1102	785	8405	125	0.01	2.37	2.44
0-14	5.2	28.5	1.35	500	1762	4846	920	35050	2360	2.47	9.20	12.22

Soil Profile No. 66 SALT WATER MARSH PEATY MUCK

Sample site located 100 feet from the north shore of Bay Bourbeaux; T.20 S., R.19 E., Terrebonne Parish.

0-6"	Black (5Y 2/1) mucky clay.
6-18"	Black (5Y 2/1) muck matrix containing 20 per cent medium and coarse fibrous peat; pH 8.0.

Dominant Vegetation: oystergrass 18 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	6.8				124	909	312	7025	140	0.06	1.91	2.13
0-18	5.7	30.6	1.73	490	1482	2317	994	36500	2250	0.33	10.88	11.76

Soil Profile No. 67 SALT WATER MARSH PEATY MUCK

Sampled 2 miles northeast of Deep Saline and 2 miles northwest of Cocodrie Station; Sec. 1, T.21 S., R.17 E., Terrebonne Parish.

0-12"	Very dark brown (10YR 2/2) muck matrix containing 40 per cent very dark brown fine fibrous peat and light brownish-gray (10YR 6/2) coarse fibrous parts of oystergrass; pH 7.5.
12-48"	Black (5Y 2/1) muck matrix containing 10 per cent dark reddish-brown (5YR 3/4) fine fibrous peat and 20 per cent light brownish-gray (10YR 6/2) coarse fibrous peat; pH 7.5.
48-120"	Dark gray (5Y 4/1) clay; pH 8.0.
120-156"	Dark gray (5Y 4/1) very fine sand; pH 8.0.

Dominant Vegetation: oystergrass 18 inches tall, with black rush 48 inches tall.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	7.1				131	934	293	2770	182	0.01	2.02	2.06
0-12	6.2	31.6	0.63	476			1537	35400	1634	0.99	8.53	9.90
12-48	6.2		1.12	456			2640	67400	1380	1.73	15.91	17.96
48-120	7.4								410	0.41	3.42	3.93
120-156	7.9								160	0.00	0.74	0.78

Soil Profile No. 68 SALT WATER MARSH PEATY MUCK

Sample site near the shore of Deep Saline Lake; Sec. 11, T.21 S., R.17 E., Terrebonne Parish.

0-18" Very dark brown (10YR 2/2) muck containing 30 per cent fine and coarse fibrous peat.

Dominant Vegetation: oystergrass 24 inches tall, with saltgrass 24 inches tall, glasswort 18 inches tall and black rush 36 inches tall.

Chemical Characteristics

Depth, Inches	pH	Organic Matter %	Total Sulphur %	Total P ppm	Water soluble cations, anions and salts							
					Ca	Mg	K	Na	CO_3	Na_2SO_4 %	NaCl %	Total Salts %
					ppm							
Soil Water	7.3				162	1127	540	8890	188	0.10	2.50	2.69
0-18	5.1	38.8	2.02	460	2270	6413	116	49975	3250	0.87	13.72	15.35

Soil Profile No. 69 SALT WATER MARSH PEATY MUCK

Sampled from near Bayou Jones; 1½ miles east of Mud Lake; northeastern part of Sec. 1, T.21 S., R.15 E., Terrebonne Parish.

0-10"	Very dark brown (10YR 2/2) muck with a surface mat of coarse fibrous parts of oystergrass; pH 8.0.
10-48"	Very dark brown (10YR 2/2) medium and coarse fibrous mucky peat; pH 8.0.
48-84"	Dark gray (5Y 4/1) mucky clay; pH 8.2.
84-120"	Dark gray (5Y 4/1) very fine sand; pH 8.2.

Dominant Vegetation: oystergrass and black rush, with saltgrass and sand rush.

Chemical Characteristics

					Water soluble cations, anions and salts							
Depth,		Organic	Total	Total								Total
		Matter	Sulphur	P	Ca	Mg	K	Na	CO_3	Na_2SO_4	NaCl	Salts
Inches	pH	%	%	ppm	----------	----------	ppm	----------	----------	%	%	%
Soil Water					88	563	112	1810	142	0.01	1.99	2.05
0-10	7.2	40.0	1.99	348	1432	4419	1500	39460	330	0.04	10.10	10.22
10-48	7.0	43.3	2.37	530			2204	55600	425	0.01	13.88	13.99
48-84	7.8	15.9							320	0.00	5.21	5.28
84-120	7.8	1.4							80	0.00	0.97	0.99

Chemical Properties of the Water and the Organic Soils and Clays of the Coastal Marshlands

The results of the chemical analysis of samples of soil water and soil materials are discussed in the following section. The water samples were taken from holes in the upper 12 inches of the soil material, at the locations where the samples of soil materials were collected.

Reaction of the Soil Water

The pH values of water sampled from the organic soil materials, peats and mucks, range from strongly acid, pH 5.1, to moderately alkaline, pH 8.3. Water samples from the Fresh Water organic soil materials have pH values ranging from strongly acid, pH 5.1, to neutral, pH 7.1. The pH values of water from the Brackish peat, muck, mucky peat and peaty muck range from neutral, pH 6.6 to moderately alkaline, pH 8.3. The high value, pH 8.3, is for water from profile No. 46—Brackish peat. The pH values of water samples from Salt Water mucks and peaty mucks range from slightly acid, pH 6.3, to neutral, pH 7.3. Water samples from the clay-textured soil materials have pH values ranging from strongly acid, pH 5.4, for the Fresh Water clays to neutral, pH 7.2, for the Brackish clays and neutral to moderately alkaline, pH 7.0 to 7.9, for the Salt Water clays.

Water Soluble Cations, Anions and Salts of the Soil Water

The amounts of water soluble calcium present in the water samples are generally low, ranging from 13 to 329 ppm for all of the water samples. The lowest amounts of calcium, 13 to 36 ppm, are present in the soil water from Fresh Water soil materials. The highest concentration of calcium, 88 to 319 ppm, is present in the water samples from Salt Water soil materials. The values for calcium present in water from Brackish soil materials range from 47 to 329 ppm for the peaty mucks, peats, mucks and mucky peats to 40 ppm for the clayey mucks and 61 to 92 ppm for the water from Brackish mucky clays and clays.

The water soluble magnesium present in the soil water samples increases in amount with the increasing salinity of the soil materials, with the lowest values, 20 to 240 ppm, present in water samples from Fresh Water materials. The highest values, 965 to 2,565 ppm, are present in the water samples from the Salt Water clays, with 1,046 to 1,783 ppm present in the water from Salt Water mucky clays and 2,237 ppm present in the water from Salt Water clayey mucks. Intermediate amounts of magnesium are present in water samples from the Brackish soil materials.

The amounts of potassium present in the samples of soil water increase as the salinity of the soil material increases. The lowest amounts, 3 to 65 ppm, are present in water samples from Fresh Water soil materials, and the highest amounts, 112 to 785 ppm, are present in water samples from the Salt Water soil materials. Intermediate amounts, 61 to 398 ppm, are present in the water samples from Brackish soil materials.

The amounts of water soluble sodium present in the water samples from Salt Water soil materials range from 954 to 11,200 ppm, with lower amounts, 20 to 650 ppm, present in the water samples from Fresh Water soil materials. Water samples from Brackish soil materials contain 700 to 5,900 ppm of water soluble sodium.

The amounts of CO_3 present in the soil water samples range from the highest values, 88 to 8,975 ppm, for water samples from Salt Water soil materials to low values, 45 to 250 ppm, for water samples from the Fresh Water soil materials. Intermediate values of 60 to 225 ppm of CO_3 are present in the water samples from Brackish soil materials.

Values for the percentage of Na_2SO_4 present in the water samples are highest, 0.27 per cent, in water from the Brackish and Salt Water soil materials. None to low amounts of Na_2SO_4, 0 to 0.17 per cent, are present in the water from Fresh Water soil materials.

The values for sodium chloride present in the water samples range from the highest amounts, 2.05 to 4.96 per cent, present in water from the Salt Water soil materials, to the lowest amounts, 0.01 to 0.32 per cent NaCl, in the water from Fresh Water soil materials. The NaCl content of water from Brackish soil materials ranges from 0.51 to 1.93 per cent.

The total salt content of the water samples ranges from high values, 2.05 to 5.27 per cent, for water from Salt Water soil materials to low values, 0.03 to 0.56 per cent, for water from the Fresh Water soil materials. Water from the Brackish soil materials contains 0.53 to 1.93 per cent total salts. The basic cations, anions and salts increase in amounts as the salinity of the soil materials and soil water increases.

Reaction of the Soil Materials

The pH values of the surface layers to a depth of approximately 16 inches range from extremely acid, pH 4.0, to moderately alkaline, pH 8.2, for all of the profiles. The surface layers of Brackish and Salt Water soil materials generally have higher pH values than the surface layers of the Fresh Water soil materials.

The pH values for the subsurface layers, at a depth of approximately 16 to 30 inches, range from extremely acid, pH 4.4, to moderately alkaline, pH 8.2, with an extremely low value, pH 2.6, for the subsurface horizon of profile No. 44—Brackish Marsh muck, which also contains 6.77 per cent Na_2SO_4. In general, the pH values of the subsurface layers are lower for the Fresh Water soil materials and higher for the Brackish and Salt Water soil materials.

Organic Matter Content of the Soil Materials

The surface layers of the organic soils—peats and mucks—usually contain the largest amounts of organic matter, but considerable amounts are present in some subsurface and substrata layers. The highest values for the percentage of organic matter, 36 to 75 per cent, are present in the surface layers of the Fresh Water peats, mucky peats and peaty mucks. Surface layers of the Brackish peaty mucks, mucky peats, peats and mucks and the Salt Water mucks and peaty mucks contain from 28 to 62 per cent organic matter. The lowest amounts of organic matter, 4.1 to 10.2 per cent, are present in the surface layers of the clay-textured soil materials. Surface layers of the mucky clays contain 11.9 to 15.1 per cent organic matter. The organic matter contents of the surface layers of clayey muck profiles range from 17 to 25 per cent.

The subsurface layers of the clay-textured soil materials contain from 2.8 to 37 per cent organic matter, and the values for clayey muck and mucky clays range from 7.2 to 27 per cent. The largest amounts of organic matter, 13.3 to 76 per cent, are present in the subsurface layers of the profiles of Fresh Water, Brackish and Salt Water peats and mucks.

Sulphur Content of the Soil Materials

The values for the total amounts of sulphur present in the surface layers of the soil materials are highest in the profiles of organic soil materials, with 0.06 to 1.08 per cent present in the Fresh Water organic soil materials, 0.79 to 3.74 per cent present in the Brackish organic soil materials and 0.63 to 3.97 per cent present in the profiles of Salt Water organic soil materials. A high value of 3.97 per cent sulphur is present in the surface layer of profile No. 64—Salt Water Marsh clayey muck. The surface layer of profile No. 47—Brackish Marsh peat contains 3.11 per cent sulphur, and the pH is 4.0. The surface layers of profiles of clay-textured soil materials contain 0.04 to 0.87 per cent sulphur.

The values for total sulphur present in the subsurface layers range from 0.20 to 3.18 per cent for profiles of organic soil materials and from 0.01 to 0.80 per cent for the subsurface layers of the clay-textured soil materials. The profiles of clayey muck and mucky clay contain 0.30 to 3.48 per cent sulphur in the subsurface layers. The total sulphur present in the subsurface layer of profile No. 62—Salt Water Marsh clayey muck is 3.48 per cent.

Phosphorus Content of the Soil Materials

The values for phosphorus present in the surface layers of the profiles of organic soil materials are high, 140 to 1,200 ppm, with the highest value, 1,200 ppm, present in the surface layer of profile No. 18—Fresh Water Marsh mucky peat. The phosphorus contents of the surface layers of profiles of clayey muck, mucky clay and clay range from 140 to 623 ppm.

The phosphorus contents of the subsurface layers of the profiles of peat and muck soils range from 134 to 1,020 ppm. Profiles of clay soil materials have 124 to 310 ppm of phosphorus in the subsurface layers. Mucky clay and clayey muck soil materials contain 360 to 580 ppm of phosphorus in their subsurface layers.

Water Soluble Cations, Anions and Salts of the Soil Materials

The values for water soluble calcium present in the surface layers of the profiles of muck and peat soil materials range from 413 to 3,920 ppm, with the highest value, 3,920 ppm, present in profile No. 47—Brackish Marsh peat. High amounts of calcium are present in the surface layers of the profiles of Brackish peats and mucks, 495 to 3,920 ppm, and Salt Water peats and mucks, 1,432 to 2,270 ppm. Lower amounts of calcium, 413 to 1,088 ppm, are present in the surface layers of profiles of Fresh Water peats and mucks. The lowest amounts of calcium, 202 to 667 ppm, are present in the surface layers of profiles of Fresh Water clay, Brackish clays, clayey mucks and mucky clays and Salt Water clays.

The highest amounts of calcium in the subsurface layers are present in all the profiles of the organic soils, 129 to 3,294 ppm. The clay-textured soil profiles have subsurface layers containing 193 to 696 ppm of calcium, with the exception of profile No. 11—Fresh Water Marsh clay, which has a calcium content of 2,620 ppm. Values for calcium present in the subsurface layers of the profiles of mucky clays and clayey mucks range from 192 to 2,215 ppm.

The values for magnesium present in the surface layers of the profiles of organic soil materials range from 5 to 3,114 ppm for the Fresh Water peats and mucks to 100 to 4,546 ppm for the Brackish peats and mucks and 2,317 to 6,413 ppm for the Salt Water peats and mucks. The surface layers of the clay-textured profiles contain varying amounts of magnesium, ranging from 625 ppm present in the Fresh Water clays to 411 to 890 ppm in the Brackish clays and 398 to 2,404 ppm in the Salt Water clays. The magnesium content of the surface layers of Brackish and Salt Water mucky clays and clayey mucks ranges from 525 to 5,750 ppm.

There is an irregular distribution of magnesium in the subsurface layers of profiles of Fresh Water peats and mucks, with the values ranging from 5 to 2,997 ppm. The largest amounts of magnesium in the subsurface layers, 297 to 6,289 ppm, are present in the profiles of Salt Water muck clays, clayey mucks and clays and in the Brackish peats and mucks, with 317 to 6,807 ppm. The lowest values for magnesium, 150 to 779 ppm, are present in the subsurface layers of Brackish clays.

The surface layers of profiles of Brackish and Salt Water peats and mucks contain high amounts, 116 to 1,650 ppm, of potassium. Soil profiles of Salt Water mucky clays and clayey mucks contain 330 to 2,100 ppm of water soluble potassium in the surface layers. Lower values of 103 to 450 ppm of potassium are present in the surface layers of profiles of Fresh Water and Brackish clays, clayey mucks and mucky clays.

The highest amounts of potassium present in the subsurface layers are 370 to 2,430 ppm in the profiles of Brackish and Salt Water peats and mucks and 413 to 1,335 ppm in the profiles of Salt Water clays. The lowest amounts of potassium in the subsurface layers are 211 to 472 ppm in profiles of Fresh Water clay and Brackish clays, clayey mucks and mucky clays.

The sodium content of the surface layers of profiles of clay-textured soil materials ranges from 1,780 ppm for the Fresh Water clay to 5,680 to 11,600 ppm for the Brackish clays and higher amounts of 10,375 to

18,550 ppm for the Salt Water clays. The surface layers of the profiles of organic soil materials contain high to very high amounts of sodium, ranging from 710 to 20,350 ppm for the Fresh Water peats and mucks to 7,461 to 40,500 for the Brackish peats and mucks and 35,400 to 49,975 ppm for the Salt Water peats and mucks. Surface layers of the Brackish and Salt Water clayey mucks and mucky clays contain from 4,800 to 47,100 ppm of sodium.

High amounts of sodium are present in the subsurface layers of the profiles of Salt Water peats and mucks, 55,600 to 67,400 ppm, the Salt Water mucky clays and clays, 12,000 to 55,800 ppm, and the Salt Water clays, 12,100 to 26,700 ppm. The subsurface layers of the Brackish peats, mucks, mucky clays and clays have sodium contents ranging from 3,015 to 71,500 ppm. The subsurface layers of the profiles of Fresh Water soil materials contain lower amounts of sodium, and the values range from 1,610 ppm for the Fresh Water clay to 1,480 to 18,250 ppm for the Fresh Water peats and mucks.

The carbonate contents of the surface layers of profiles of organic soil materials range from 40 to 1,610 ppm for the Fresh Water peats and mucks to 850 to 3,090 ppm for the Brackish peats and mucks and 330 to 3,250 ppm for the Salt Water peats and mucks. Lower amounts of CO_3, 215 to 535 ppm, are present in the surface layers of the profiles of Brackish and Salt Water clays, clayey mucks and mucky clays. The lowest amount of CO_3, 115 ppm, is present in the surface layer of the profile of Fresh Water clay.

The highest amounts of CO_3 present in the subsurface layers are 160 to 2,060 ppm in the profiles of Fresh Water peats and mucks, 80 to 2,064 ppm in the profiles of Brackish peats and mucks and 425 to 1,380 ppm in the profiles of Salt Water peats and mucks. Lower amounts of CO_3, 125 to 688 ppm, are present in the subsurface layers of all profiles of clays, clayey mucks and mucky clays.

There is a rather uniform distribution of small amounts, 0.10 to 0.60 per cent, of Na_2SO_4 throughout all the soils of this study. Most values for the percentage Na_2SO_4 present in the surface layers range from 0.01 to 0.69 per cent. A high value, 3.74 per cent, is present in the surface layer of profile No. 47—Brackish Marsh peat, and 2.64 per cent Na_2SO_4 is present in the surface layer of profile No. 36—Brackish Marsh peaty muck. The surface layers of Brackish and Salt Water soil material usually contain higher amounts of Na_2SO_4 than the surface layers of Fresh Water soil materials.

The values for percentage of Na_2SO_4 present in the subsurface layers range from 0.01 to 1.97 for most profiles. High values of 6.77 and 3.65 per cent Na_2SO_4 are present in the subsurface layers of profile No. 44—Brackish Marsh muck and profile No. 63—Salt Water Marsh clayey muck, respectively.

The sodium chloride contents of the surface layers of the soil materials increase from the Fresh Water to Brackish to Salt Water areas of the coastal marshlands. The sodium chloride contents of the surface layers of peat and muck soil materials range from 0.16 to 4.35 per cent for the Fresh Water peats and mucks to 2.87 to 10.22 per cent for the Brackish peats and mucks and 8.53 to 13.72 per cent for the Salt Water peats and mucks. The percentages of sodium chloride present in the surface layers of the clay-textured soil materials are: Fresh Water clay, 0.62 per cent; Brackish clays, 1.42 to 2.34 per cent; and Salt Water clays, 2.13 to 4.58 per cent.

The values for total sodium chloride present in the subsurface layers of the organic soil materials range from the lowest amounts, 0.07 to 3.36 per cent, in the Fresh Water peats and mucks to the highest amounts, 13.88 to 15.91 per cent, in the Salt Water peats and mucks. The subsurface layers of the Brackish peats and mucks have intermediate amounts, 1.03 to 14.35 per cent, of sodium chloride. The sodium chloride present in the subsurface layers of the clay-textured soil materials ranges in value from 0.84 to 1.96 per cent for the Brackish clays to 2.51 to 9.28 per cent for the Salt Water clays.

The percentages of total salts determine the salinity classes and increase in value from the areas of Fresh Water Marsh to the areas of Salt Water Marsh. The total salts present in the surface layers of the Fresh Water peats and mucks range from 0.16 to 5.00 per cent, with the Brackish peats and mucks containing 3.26 to 12.22 per cent and the Salt Water peats and mucks containing 9.90 to 15.35 per cent. The clay-textured soil materials have surface layers containing the following amounts of total salts: Fresh Water clay, 1.09 per cent; Brackish clays, 1.53 to 2.66 per cent; and Salt Water clays, 2.19 to 4.71 per cent. The high value, 15.35 per cent total salts, is present in the surface layer of profile No. 68—Salt Water Marsh peaty muck, which contains 49,975 ppm of water soluble sodium. The values for total salts present in the subsurface layers of the peat and muck soil materials range from 0.10 to 4.83 per cent for the Fresh Water peats and mucks to 1.33 to 14.53 per cent for the Brackish peats and mucks and 13.99 to 17.96 per cent for the Salt Water peats and mucks. The subsurface layers of the clay-textured soil materials have total salt contents of 2.65 per cent in the Fresh Water clay, 0.96 to 2.91 per cent in the Brackish Water clays and 2.72 to 9.30 per cent in the Salt Water clays. The largest amount of total salts, 19.47 per cent, is present in the subsurface layer of profile No. 56—Salt Water Marsh mucky clay.

Since the values for water soluble salts were calculated on the basis of air-dry samples, high values are reported on laboratory analysis of soil materials containing large amounts of organic matter and having low bulk-density values. Values for the salt content of the soil water samples agree in general with the salt tolerance of the plants growing in the different areas of coastal marshlands classified as Fresh Water, Brackish and Salt Water Marshes.

Mineralogical Properties of the <2 Microns Clay for Selected Horizons of Soil Materials of the Coastal Marshlands

The results of X-ray diffraction analysis of samples of the <2 microns clay from selected horizons of profiles of soil materials are given in Table 7. These analyses indicate that the <2 microns clay fractions are

Table 7.-The relative quantities of clay minerals present in selected horizons of coastal marshland soils.

Profile No.	Salinity and Texture	Depth, Inches	Horizon color and texture	Dominant clay mineral content*
11	Fresh Water Marsh mucky clay	0-6	dark gray mucky clay	M_1 I_2 K_2 Q_3
16	Fresh Water Marsh peaty muck	24-48	gray clay	M_1 I_2 K_2 Q_3
22	Fresh Water Marsh mucky peat	10-18	gray clay	M_1 K_2 I_2 Q_3
23	Brackish Marsh clay	20-30	black mucky clay	M_1 K_2 I_2 Q_3
26	Brackish Marsh clay	0-16	very dark brown clay	M_1 I_2 K_2 Q_3
		16-30	very dark gray clay	M_1 I_2 K_2 Q_3
		30-42	dark gray fine sandy loam	M_1 K_2 I_2 Q_3
51	Salt Water Marsh clay	0-5	very dark grayish brown clay	M_1 I_2 K_2 Q_3
58	Salt Water Marsh mucky clay	0-4	very dark gray mucky clay	M_1 I_2 K_2 Q_3
		4-24	very dark gray mucky clay	M_1 I_2 K_2 Q_3

*Key to clay mineral composition of the <2 microns clay:

Abbreviation of names
M = montmorillonite
I = illite
K = kaolinite
Q = Quartz

Indication of quantity
1 = Abundant component ($>40\%$)
2 = Less abundant component (10-40%)
3 = Minor component ($<10\%$)

dominated by montmorillonite, more than 40 per cent, and that they contain considerable amounts, 10 to 40 per cent, of both illite and kaolinite. Quartz is a minor constituent of the <2 microns clay fractions. There is no indication that soil texture or salinity influences the kind or content of the different clay minerals. In a broad sense, all of the young, recently deposited materials of the coastal marshlands may be considered to be parent materials, occupying sites where conditions are generally unfavorable for the development of genetic soil horizons. The differences in the assemblages of clay minerals in the soil profiles may be due to differences in the mineral composition of the recent alluvial sediments from different sources, and not the result of weathering after the materials were deposited.

Definitions of Soil Horizon Symbols

In general description of soils, the terms commonly used are surface soil (A horizon), subsoil (B horizon) and substratum (C horizon). Symbols used in detailed descriptions of soils are A, B and C for the different soil horizons and arabic numbers and lower case letters for subdivisions of the soil horizons, as listed below.

Ap — a surface mineral soil layer which has been disturbed or mixed as by plowing.
Ap_1, Ap_2 — subdivisions of the Ap horizon due to differences in one or more of the following characteristics: color, texture, structure, consistence.
A_b — a buried A horizon.
A-C — a horizon transitional between the A and C, and having properties of both.
B_{2t} — the layer of maximum accumulation of silicate clay that has concentrated by leaching from soil horizons above.
B_{21t}, B_{22t} — subdivisions of the **B_{2t}** due to differences in one or more of the following characteristics: color, texture, structure, consistence.
B_3 — a transition horizon between B and C, but dominated by characteristics of the B.
C — a mineral soil horizon that lies outside the zone of major biological activity; relatively little affected by soil forming processes; either like or unlike the material from which the solum is formed.
C_1, C_2 — subdivisions of the C horizon, each requiring a separate description because of differences in color, texture, structure or consistence.
C_g — dominantly gray, strongly gleyed C horizon.
C_{1g}, C_{2g} — subdivisions of **C_g** due to differences in one or more of the following characteristics: color, texture, structure, consistence.

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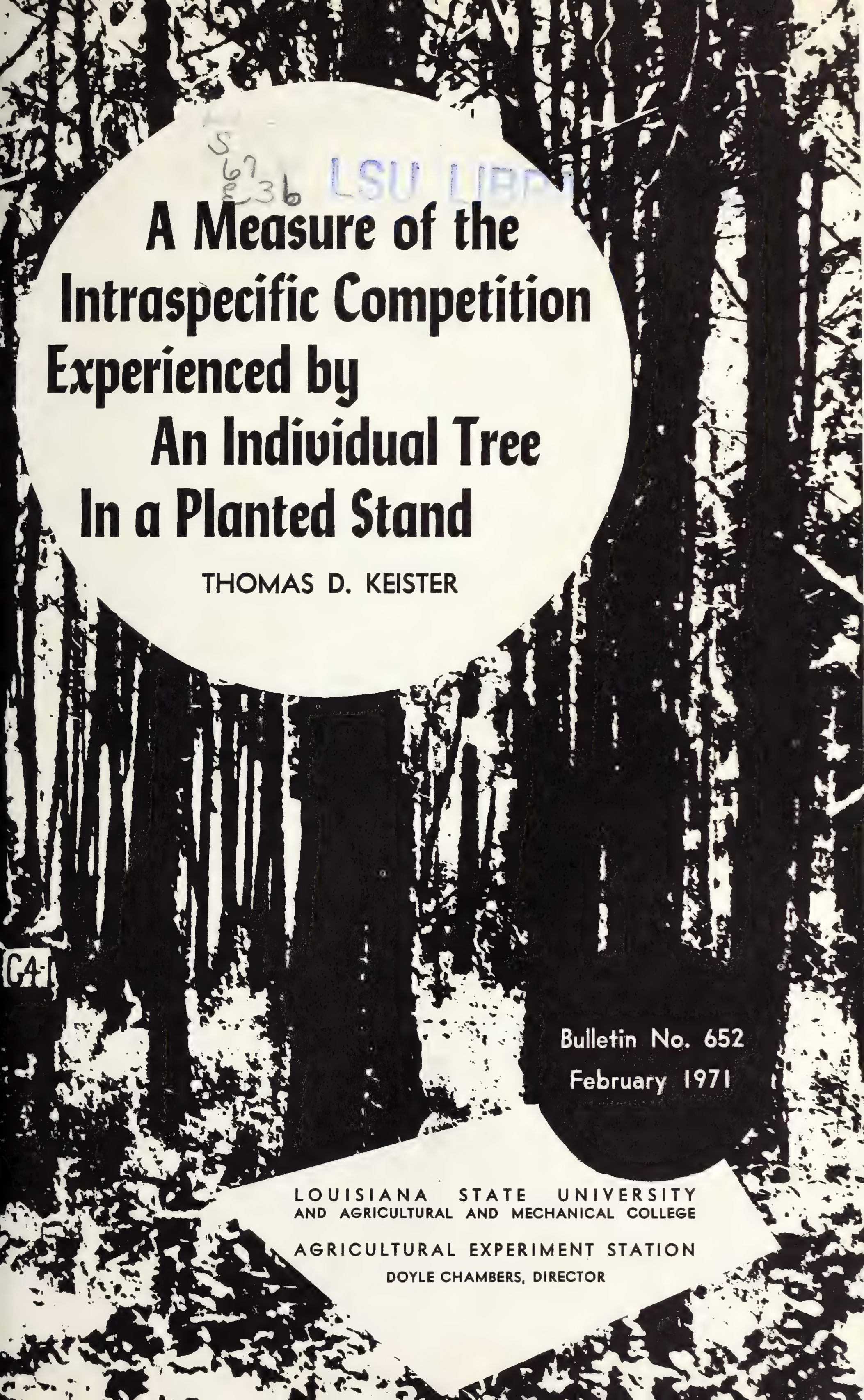
A Measure of the Intraspecific Competition Experienced by An Individual Tree In a Planted Stand

THOMAS D. KEISTER



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A Measure of the Intraspecific Competition Experienced by an Individual Tree In a Planted Stand

THOMAS D. KEISTER[1]

Introduction

One of the greatest impediments to thinning research is the large area which must be provided for the various treatments. For this reason most thinning studies have an inadequate number of replications with which to compare treatments. Another impediment is the difficulty of defining a range of thinning regimes by mathematical functions suitable for statistical analyses (Dawkins, 1960). Osborne (1939) has suggested that the first impediment may be overcome by using individual trees rather than stands as units of study. Regression techniques may be used to compare the development of individual trees that have received particular amounts of release by thinning. If individual tree measurements are used rather than stand measurements, much more information can be learned with less involvement of stands and land area. Thinning studies are usually more concerned with differences in degree of thinning rather than in kind of thinning, and individual tree measurements lend themselves to this type of study (Smith, 1959).

Probably the main reason that thinning studies have more often been concerned with stands than with single trees is the difficulty, already mentioned, of defining the degree of thinning. Wicht (1948) felt that thinning degree could be expressed in terms of stems per acre. Hummel replied in this same article that experience in Great Britain has shown that the number of stems per acre is a suitable variable for experiments designed to find the most suitable height or age at which to start thinning. However, in experiments where thinning is started on all plots at the same age and differs only in severity, such a measure is not as good as an index of stand density which considers mean basal area and height as well as the number of stems. Worthington *et al.* (1962) tried to measure thinning intensity with a specified stand-density index but found this was not satisfactory since cutting was not uniformly distributed over the entire range of tree diameters. Johnston and Waters (1961) stated that it is impossible to give a definition of a thinning grade which can be widely applied both qualitatively and quantitatively. Wicht (1936) and Vezina (1962) have both mentioned the need for research to find a measure of stand density.

This study was concerned with finding some measure of stand density, or of thinning intensity, that could be objectively applied to individual trees within a stand. It was felt that if the competition an individual tree was receiving from surrounding trees could be objectively measured, then the degree of thinning could be measured by determining the reduction in this competition following the thinning. Such a measure of competition would be a measure of stand density if it could describe the degree of crowding of individual trees within the portion of the area actually stocked with trees (Smith and Bailey, 1964).

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The space available to a tree has been used by many workers as a measure of competition. Krajicek and Brinkman (1957) developed a "crown-competition factor" which is based on the area in the stand utilized by each tree crown. Brown (1965) computed the area potentially available to each tree by determining the smallest polygon that could be obtained by erecting horizontal bisectors perpendicular to the horizontal lines joining the center of the subject tree to the centers of the neighboring trees.

Jack (1967) developed a competition factor by comparing the sum of the heights of all of the effective neighbor trees (as defined by Brown, 1965), weighted by the proportion they contribute to the area of the polygon surrounding the sample tree, to the height of the sample tree.

One of the first to study individual tree competition was Staebler (1951), who assumed that the growing space occupied by an individual tree was circular and that the radius of the area was related to the diameter of the tree. Zones of competition occurred wherever two of these circular areas overlapped. He believed that the competition exerted upon an individual tree was directly proportional to the amount of overlap of its circle.

Newnham (1966) and Gerrard (1969) both used Staebler's basic ideas but were able to make further advances in the approach. Both men tried relating the radii of the competition circles to tree diameter, and Newnham also tried relating this radius to crown width. However, none of the resulting measures of competition contributed significantly to growth-prediction equations when combined with diameter and other tree and stand parameters. Gerrard was working in natural oak-hickory stands in Michigan and he believed that better results would have been found if the work had been done in single-species stands, preferably plantations, where the number of factors controlling the performance of individual trees is less.

Opie (1968) expressed the relative area of overlapping circles in terms of basal area per acre. He noted that a circular zone of the influence existed around each tree. The radius of this circle varied both with site and with tree size. Opie developed a method for measuring the basal-area density of a given tree by determining the area of overlap of a subject tree's zone of influence by adjacent trees, combined with the number of trees involved in this overlap. An angle gauge was used to sample for overlap throughout the zone of the subject trees.

This paper presents a method for measuring the intraspecific competition that an individual tree is experiencing in an even-aged, single-species forest stand.

Development of a Competition Index Equation

Basic Theory

The method presented in this paper is similar to those developed by Newnham, Gerrard, and Opie in that overlapping circles are also used. The basic premise is that growth made by an individual tree varies inversely with the ratio of the size of the individual to the size of the competing tree and varies directly with the horizontal distance between the individual tree and the competing tree.

Each tree interacts with all of the environmental variables in a certain area that surrounds it. For example, its crown shades a certain area and its roots occupy a certain area from which nutrients and water are taken. The combined area of interaction by a tree can be called the "circle of influence" (Zinke, 1962), and it seems reasonable to assume that this area approximates a circle (both roots and limbs, if not impeded, tend to grow away from the tree at nearly an even rate in all directions). The radius of this circle of influence will vary in size according to the species, character of soil, genetic potential, and the overall size of the tree. A zone of competition exists wherever these areas overlap, and the effect of this competition on either of the trees at the center of the influence circles is theoretically proportional to the ratio of the area of the competition zone to the area of either circle of influence.

The amount of competition received by any one tree from a single neighbor depends on the size of the individual (which determines the size of its circle of influence) and on the portion of this circle that is overlapped by the neighbor's circle of influence. The competition received by one tree (hereafter called a sample tree) from one other tree, then may be defined as:

$$I_{ik} = C_{ik}/\pi K_k^2 \qquad (1)$$

where: I_{ik} = competition received from the i th competing tree by the k th sample tree,
C_{ik} = the area in the zone of competition, and
K_k = the radius of the influence circle of the tree receiving the competition (Figure 1).

When a tree has its circle of influence overlapped by the circles of several other trees, then the amount of competition it receives will be equal to the sum of the ratios of the areas of all the competition zones to the area of the circle of influence of that individual tree. This total competition or competition index for the k th sample tree may be defined as:

$$\sum_{i=1}^{n} I_{ik} = (1/\pi K_k^2) \sum_{i=1}^{n} C_{ik} \qquad (2)$$

The area of C_{ik} may be calculated as:

$$C_{ik} = K_k^2 \arctan \left[U/(X_{ik}^2 + B)\right]$$

$$+ R_i^2 \arctan \left[U/(X_{ik}^2 - B)\right] \quad - U/2$$

where: R_i = the radius of the influence circle of the i th competing tree,

X_{ik} = the horizontal distance between the k th sample tree and the i th competing tree,

$$B = K_k^2 - R_i^2$$

$$U = \left[X_{ik}^2 (2A - X_{ik}^2) - B^2\right]^{1/2}$$

$$A = K_k^2 + R_i^2$$

i = 1, 2, 3, . . . , n competing trees, and

k = the k th tree of m sample trees (Fig. 1).

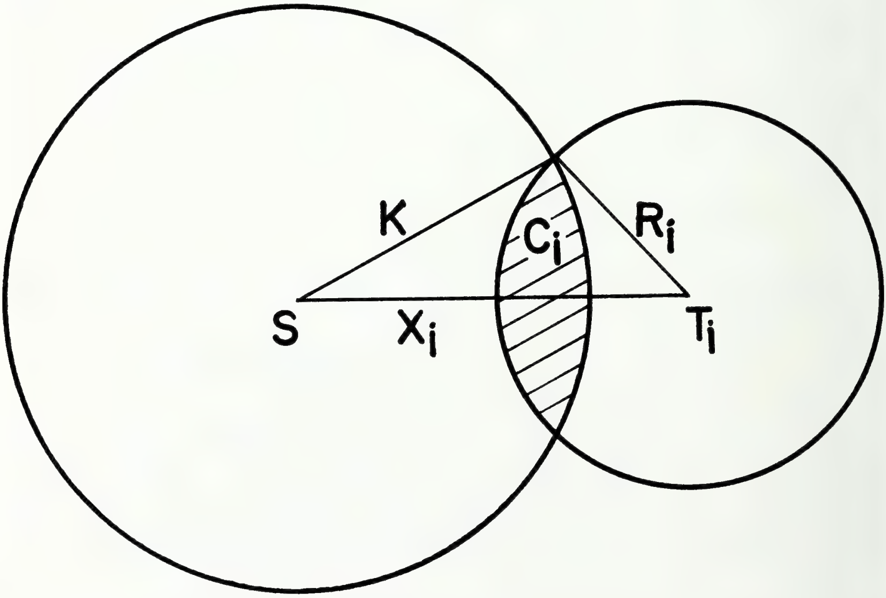

Figure 1.—Zone of competition between two trees. S = sample tree; K = radius of circle around tree S; X_i = distance between trees S and T; T_i = competing tree; R_i = radius of circle around T_i; C_i = zone of competition (diagonal lines).

The value for the competition index decreases with increasing distance between trees and as the ratio of the sum of the areas of overlap to the sample tree's circle area decreases.

The radius of a tree's circle of influence (K_k or R_i) is related to the size of the tree. If this radius is large, it is likely that the number of overlapping trees (n) will also be large, since a large circle is likely to overlap with more circles than is a small circle. However, it is possible that the k th sample tree and the k+1 th sample tree might have equal index values even though $n_k < n_{k+1}$. The k th sample tree will have a few competing trees, each contributing a large part of I_k, while the k+1 th tree will have many competing trees, each contributing a small part of I_{k+1}. It was therefore decided that the variable $(I/n)_k$ should also be considered in an equation for predicting growth.

Diameter growth is usually well correlated with the tree's diameter at the start of the growth period. That is, large trees generally make more diameter growth than small trees of the same age. Any measure of the effects of competition on growth should also consider this factor. Therefore initial diameter was included in the equation with the competition variables.

The growth equation selected for testing with field data was:

$$G_a = b_0 + b_1 I + b_2 n + b_3 d + b_4 (I/n) \qquad (3)$$

where: G_a is the sample tree diameter growth for a years,

I is defined by equation 2 and equals $\sum_{i=1}^{n} I_{ik}$,

n is the number of competing trees,

d is the diameter of the sample tree at the start of the growth period, and the

b_i's are partial regression coefficients.

It was believed that some combination of these variables would account for a considerable portion of the variation in growth.

Determining the Radius of Influence

The major problem still to be solved, before the method could be field-tested, was how to determine the proper radius of a tree's influence circle. Both Newnham (1966) and Bella (1969) set this radius equal to a function of the crown radius. However, crown radius is only one parameter of tree size and it may not truly indicate the overall size of the tree. Newnham (1966), and also Gerrard (1969), used a function of tree diameter to determine the radius of the influence circle. Diameter, however, like crown width, is only one of the parameters of tree size.

In most even-aged stands there is a relationship between the stem diameter and the total height (Curtin, 1964; Czarnowski, 1961), but this relationship is modified by stand density and also by thinning treatment. Trees of the same age growing on similar sites should differ in their relationship of height to diameter according to differences in competition the individual trees have experienced in the past. A similar relationship also exists between diameter and crown radius. That is, larger trees will tend to have wider crowns. Height, diameter, and crown radius have all been used as expressions of tree size. It seemed that a combination of these measures would be a better reflection of tree size than any single measure.

It is very difficult to measure accurately the height and crown radius of every tree. However, because of the relationship between these factors and diameter, it was theorized that curves of mean height and mean crown radius as functions of diameter could be used to define the size of a tree of given diameter. The problem then was to find how best to use these variables as a meaningful expression for the radius of the influence circle. Two approaches were used.

The first approach was to assume that the radius would be proportional to the total height of a tree. That is, the radius for any tree could be defined as $T = Zh$, when Z is a proportionality value that would be constant for a given species, site, and age group, and h is the total height and is related to diameter. If the tree with radius T is selected as a sample tree, $T = \mathbf{K}_k$; otherwise $T = \mathbf{R}_i$.

The second approach was to assume that the size of a tree's live crown could be used to express tree vigor. It was felt that if two trees are equal in diameter and height the one that has the larger crown will be the most vigorous and should have the larger influence circle. In order to determine the radius by this approach it was necessary to consider diameter, total height, crown radius, and length of live crown.

An attempt was made to correlate the dead-limb length (i.e., height to lowest live limb) to diameter, as was done with total height and crown radius. On the plots used in this study, at least, no such relationship was found. Instead the dead-limb length was nearly constant for a given plantation, although there were differences between plantations. This meant that the tallest trees in a given stand have the longest crowns and would seem to favor the first approach, where circle radius was set proportional to tree height.

Others have noted that dead-limb length shows little relationship to tree diameter in even-aged pine stands. Stiell (1966) found dead-limb length in red pine (*Pinus resinosa* Ait.) plantations increased with age and was strongly correlated with total volume per acre and also with the ratio of average total height to the cube root of average spacing. Monterey pine (*P. radiata* D. Don.) has also shown no relation between diameter and dead-limb length (Laar, 1963). Toma (1940) made studies of Scotch pine (*P. sylvestris* L.) and reported that the crown began at about the same height on all trees in a stand, and that this height increased with increasing age. From these results it seems that dead-limb length should be rather constant in an even-aged stand and is related to the age of the stand, and perhaps also to site. Like the results reported by Stiell, the dead-limb length in this study showed a strong correlation with the ratio of average total tree height to the cube root of average spacing ($r = 0.842$).

Approach 2 called for setting the radius of the influence circle equal to some measure of the crown. It was finally decided to set the radius of a tree's influence circle equal to the distance between the tip of the tree and the intersection of a line from the base of the tree through the outer edge of the crown base and a line from the tip perpendicular to the trunk of the tree (Figure 2). Thus, if a tree of diameter d has a total height h and crown radius c, and is growing in a stand with average dead-limb length m, then the radius of the influence circle for this tree (T) can be defined as T = (hc)/m. If the relationships of height (h) and crown radius (c) to diameter (d) are known, and if the average dead-limb length for the stand is known, then T can be determined for any tree in the stand simply by measuring its diameter. Tall trees and trees with wide crowns will have longer circle radii than short or narrow-crowned trees.

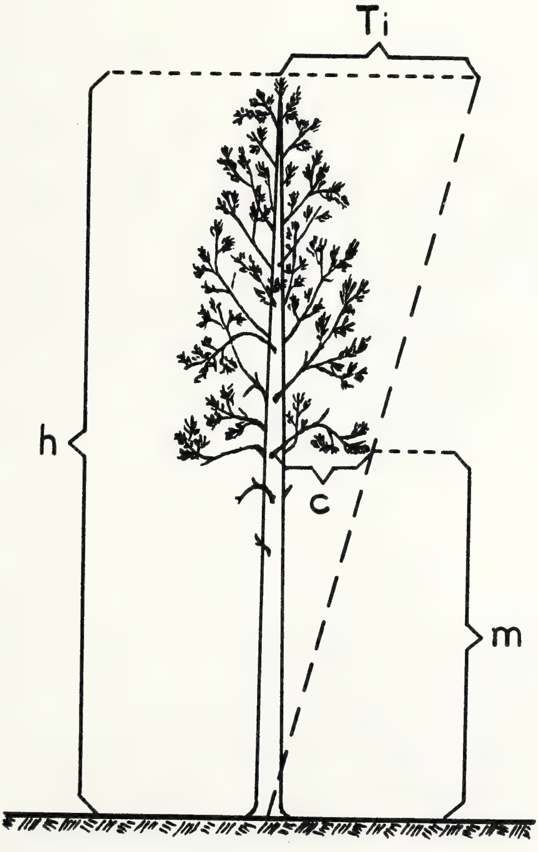

Figure 2.—Procedure for determining the radius of a tree's influence circle (T_i), as used in approach 2, where $T_i = hc/m$; h = total tree height; c = crown radius; m = dead-limb length; T_i = radius for the i th tree's circle of influence.

Field Test of the Competition Index Hypothesis

Method

A field test of the utility of this competition index for predicting growth of individual trees was begun in October 1966 by the Louisiana State University School of Forestry and Wildlife Management in cooperation with the Agricultural Experiment Station. Three ¼-acre circular plots were located in each of seven pine plantations. Three of these plantations (G1, G2, and G3) were slash pine (*Pinus elliottii* Engelm.) that had been planted in January 1952 with 1-0 planting stock. One plantation (G7) had been planted with 1-0 loblolly pine (*P. taeda* L.) seedlings in January 1956. One plantation (G5) was a mixed slash- and loblolly-pine plantation planted with 1-0 stock in December 1953. The other two plantations were both slash pine, one (G4) planted in December 1952 and the other (G6) planted in December 1953. Initial spacing was to have been 6 feet x 8 feet, but actual spacing was sometimes quite different from that intended.

The plantations were all located in Livingston Parish, Louisiana. The plots in plantations G1, G2, and G3 were established in the winter of 1966 when the trees had completed 15 growing seasons in the field. Plots in plantations G4, G5, G6, and G7 were established during the winter of 1967 when trees on G4 had completed 15 seasons, G5 and G6 had completed 14 seasons, and G7 had completed 11 growing seasons. All plots, with the exception of those in G7, were planted by hand and have been frequently burned so that survival is quite spotty. Several plots have some volunteer trees growing in them, and all have suffered some damage from recent hurricanes, so spacing is not very regular. Most of the plantations are on average to poor sites for this area. Using 25 as a base age, site indices range from a low of 64 (G6) to a high of 88 (G7); the overall average site index is 72.4.

Plantation G7 is exceptional in several ways. It is the only plantation studied that was machine planted; hence the trees are growing in rather straight rows. There are no trees growing there that were not planted. There was a minimum amount of storm damage. The most unique fact about this plantation, however, was the unusual early growth made by some of the trees. This area was cleared and all vegetation piled and burned in 1955. Seedlings that were planted in the resulting ashes made exceptional height growth over the next three years. The average annual height growth of trees growing for three years in ashes was 3.25 feet as compared with 1.63 for trees not growing in ashes. Apparently this difference resulted from the fact that the trees planted in ashes found much more available calcium, potassium, phosphorus, and magnesium than did trees planted in ordinary soil (Applequist, 1960). From the present appearance of this plantation it seems likely that these early effects are still influencing the size of many of the trees. At least the height growth on these plots has been especially good.

A summary of conditions that existed on each plot within each plantation when the plots were established is shown in Table 1. A

Table 1.—Summary of plot conditions at the beginning of the first growing season after plot establishment
(per acre basis)

Plot No.	Trees	Basal area	Mean dbh	Top height[2]	Date plots established
	Number	*Sq.ft.*	*Inch*	*Ft.*	
		Slash Pine Plantation G1 planted 1/52			
1[1]	184	49	6.70	45	8/66
2	380	88	6.08	46	8/66
3	252	74	7.00	46	8/66
Average	272	70	6.54	45.7	
		Slash Pine Plantation G2 planted 1/52			
1	968	104	4.19	44	8/66
2	308	47	4.58	43	9/66
3	260	56	6.06	44	9/66
Average	512	69	4.58	43.9	
		Slash Pine Plantation G3 planted 1/52			
1	496	93	5.61	44	9/66
2[1]	264	61	6.33	44	9/66
3	564	99	5.47	42	10/66
Average	441	84	5.63	43.6	
		Slash Pine Plantation G4 planted 12/52			
1	580	103	5.24	48	8/67
2	520	76	4.71	43	8/67
3	272	57	5.96	44	8/67
Average	457	79	5.18	44.1	
		Slash & Loblolly Pine Plantation G5 planted 12/53			
1	400	71	5.39	47	8/67
2	436	86	5.70	46	9/67
3	376	72	5.53	47	9/67
Average	404	76	5.54	46.9	
		Slash Pine Plantation G6 planted 12/53			
1	376	67	5.36	39	9/67
2	260	64	6.56	38	9/67
3	252	55	6.10	37	10/67
Average	264	62	5.92	38.2	
		Loblolly Pine Plantation G7 planted 1/56			
1	520	99	5.62	44	10/67
2	588	112	5.65	40	10/67
3	516	118	6.24	43	10/67
Average	541	110	5.83	42.8	

[1] After thinning plot.
[2] Average height of dominant and codominant trees.

summary of the changes in plot stocking over the 2- and 3-year growth periods is shown in Table 2. There were many differences in stocking, both among plots within a plantation and among plantations. Differences in site, as expressed by top height, are not as pronounced, although again, there are differences. These differences were no accident, since plots were selected to give as wide a range of competition as possible.

All trees on each plot and all trees within 130 feet of the plot center were numbered and tagged. The diameter (dbh) of each tagged tree was measured to the nearest .01 inch. In addition, the total height,

Table 2.—Summary of cut and cumulative mortality

Plot	Initial		Cut		Mortality since plot establishment[1]		Present condition	
	Trees	Basal area	Trees	Basal area	Trees	Basal area	Trees	Basal area
	Number	*Sq.ft.*	*Number*	*Sq.ft.*	*Number*	*Sq.ft.*	*Number*	*Sq.ft.*
				Plantation G1				
1	272	72	88	24	16	1	168	60
2	380	88	0	0	84	5	296	92
3	252	74	0	0	32	7	220	80
				Plantation G2				
1	968	104	0	0	156	7	812	120
2	308	47	0	0	8	1	300	68
3	260	56	0	0	4	<1	256	72
				Plantation G3				
1	496	93	0	0	20	2	476	116
2	404	84	140	21	12	1	252	78
3	564	99	0	0	44	3	520	116
				Plantation G4				
1	580	103	0	0	16	1	564	125
2	520	76	0	0	12	1	508	90
3	272	57	0	0	0	0	272	76
				Plantation G5				
1	400	71	0	0	20	1	380	88
2	436	86	0	0	28	3	408	102
3	376	72	0	0	32	1	344	82
				Plantation G6				
1	376.	67	0	0	12	2	364	83
2	260	64	0	0	4	<1	256	78
3	252	55	0	0	0	0	252	71
				Plantation G7				
1	520	99	0	0	24	1	496	117
2	588	112	0	0	0	0	588	134
3	516	118	0	0	20	1	496	137

[1] Mortality figures are the totals lost during a 3-year period on plantations G1, G2, and G3 and during a 2-year period on all other plantations.

dead-limb length, and crown radius were measured on each tree within a plot boundary. All plot-tree diameter measurements have been repeated annually since plot establishment. The point of the initial diameter measurement was marked with small nails on opposite sides of the tree as a guide for remeasurement. The position of each tagged tree was carefully mapped.

Equations for predicting total tree height (h) and crown radius (c) from diameter were prepared for each plantation. These equations were in the forms:

$$h = a_0 + a_1 \log_{10} d \qquad (4)$$

and

$$c = b_0 + b_1 d \qquad (5)$$

where the a_i and b_i are constants for a given plantation and d is tree diameter. The average dead-limb length was also calculated for each plantation (Table 3).

Table 3.—Plantation initial average dead-limb lengths, and equations for predicting total height and crown radius from diameter

Plantation	Dead-limb length		Regression coefficients for equations[1]			
	Mean	Std. error	$h = a_0 + a_1 \log_{10} d$		$c = b_0 + b_1 d$	
			a_0	a_1	b_0	b_1
	Feet	*Feet*				
G1	18.77	.3479	6.39815	44.46339	1.45561	0.75400
G2	20.60	.3114	9.85674	42.84909	0.25184	0.95116
G3	20.50	.2199	6.47566	44.34206	0.26112	0.91195
G4	20.90	.2379	6.88504	46.67679	-0.45849	1.09744
G5	20.43	.2636	6.77684	48.00886	-0.71622	1.07419
G6	14.93	.2702	7.71892	37.35445	0.21222	1.12779
G7	19.75	.2423	8.86521	40.55955	0.52423	0.99679

[1] h = total ht; c = crown radius; d = initial dbh; and a_0, a_1, b_0 b_1 = regression coefficients.

Thirty trees, which were to be used as sample trees, were selected from each plot. These were used to determine if their future diameter growth could be predicted from the initial competition index. Sample trees were selected to cover a wide range of sizes and competition indices.

One of the aims of this study was to see if the competition index could be used to measure the effects of thinning on growth. Therefore, plot 1 of plantation G1 and plot 2 of plantation G3 were thinned immediately after all trees were measured, and after the before-thinning index values were computed (Table 4).

After-thinning index values were also computed; it was then decided to thin no more plots until the effectiveness of the index as a growth predictor could be determined.

Table 4.—Before-and after-thinning conditions and average competition index values (per acre basis)

	Before thinning			After thinning			
Plot No.	Total trees	Basal area[3]	Average index	Total trees	Basal area[3]	Average index	Sample tree basis
	Number	*Sq.ft.*		*Number*	*Sq.ft.*		*Number*
				Plantation G1			
1	272	72	5.2950	184	48	3.4784	30
2 & 3[1]	316	76	5.8019	316	76	5.8019	60
Average[2]	300	76	5.6329	272	68	5.0274	90
				Plantation G2			
Average[2]	512	68	4.4822	512	68	4.4822	90
				Plantation G3			
2	404	84	4.1761	264	60	3.2846	30
1 & 3[1]	528	96	4.5071	528	86	4.5071	60
Average[2]	488	92	4.3968	440	84	4.0996	90
				Plantation G4			
Average[2]	456	80	6.2049	456	80	6.2049	90
				Plantation G5			
Average[2]	404	76	5.3413	404	76	5.3413	90
				Plantation G6			
Average[2]	264	60	8.0498	264	60	8.0498	90
				Plantation G7			
Average[2]	540	108	7.3053	540	108	7.3053	90

[1] Unthinned plots are combined and averaged.

[2] Combined averages for 3 plots in each plantation.

[3] To nearest square foot.

Results of Field Test

Approach 1

In this approach the radius of a tree's influence was set equal to Zh, where h was the tree's total height and Z is a constant. The problem was to find the value of Z. Many different values were tried, ranging from 0.1 to 3.7 in 0.1 intervals. The resulting index values were used with the sample-tree growth for two and three years in a multiple regression analysis which dropped the least significant variable after each run of the data. The initial equation was of the form presented earlier (equation 3).

In every case diameter was the only significant variable. However, if diameter was not included, the terms I and I/n became significant. Coefficients of determination (R^2) were used to determine which equation was best for predicting growth. Some equations were able to account for 60 percent of the variation in growth. However, different values for Z gave best results on different plantations. For example, Z of 1.9 gave best results on plantations G1, G2, and G3, while a Z of 1.5 worked best in plantation G4. In fact, each plantation had its own best value for Z, and there seemed to be no way to decide which value was best before trying them all. In order for this measure of competition to be useful it is first necessary to know the value for Z. Since the only way found for determining this value was empirical, the method of approach 1 was abandoned in favor of approach 2.

Approach 2

As stated earlier, in this approach the radius of a tree's influence circle was set equal to hc/m, where h and c are total height and crown radius as defined by equations 4 and 5, respectively. The term m was a constant for trees on a particular plantation, and was set equal to the average dead-limb length. Determining the radius in this way seemed preferable to the method of approach 1, since all three of the terms h, c, and m were obtained from actual tree measures, and a combination of tree-size parameters was used.

Again, the index values for 30 trees on each plot were computed and tested against 2-year growth, using equation 3 as the initial equation. Sample trees from all plots within a plantation were combined for this test. Three-year growth data were available for trees in plantations G1, G2, G3, so this was also used with equation 3.

Results of this approach are summarized in Tables 5 and 6. As in approach 1, the initial tree diameter was usually the best single variable for predicting future diameter growth. On most plantations the initial diameter accounted for over 50 percent of the variation in 2-year diameter growth, and even a larger percentage of the variation in the 3-year diameter growth.

A statistically significant improvement in 2-year growth predictability was obtained when the index value (I) was retained in the equation. However, this improvement was not great, especially for those plantations which showed a very high correlation between growth and initial diameter.

The number of competing trees (n) was statistically significant on only plantation G3, and even there it was the least significant of the variables tested, while the fourth term, I/n, was significant only for plantations G2, G3, and G7. It was not surprising that I/n was not often significant when the simple correlations among the variables were studied. Coefficients for the correlation between diameter and I/n were all greater than .78. It was apparent from this strong relationship that diameter and I/n should probably not be combined in the same regression. It was decided to remove the term d from equation 3 and try again.

Other modifications were also considered. It seems possible that the effect of I/n on growth might be curvilinear. That is, in very open stands the effect of the competition will be very slight. In such

Table 5.—Coefficients for predicting 2-year diameter growth and the corresponding coefficients of determination (R^2)

	Independent Variables						
Constant	Initial dbh	Competition index	Competing trees	I/n	ln(I/n)	R^2	Basic equation number
	d	*I*	*n*				
		Plantation G1 (after thinning)					
0.2066	0.0691**	-0.0569**				0.5618	3
-.1153					-0.3802**	.4349	6
-.1388	.0777**					.4359	3
		Plantation G2					
.1227	.1278**	-.1041**		0.6899**		.5724	3
.6962	.0669**	-.1088**				.4955	3
1.1303		-.1311**				.3489	3
.1035	.0879**					.2709	3
		Plantation G3 (after thinning)					
-.1298	.0982**	-.0714**	0.0108*	.3851*		.6237	3
-.0214	.1020**	-.0309				.5992	3
-.1734	.1067**					.5819	3
		Plantation G4					
.1897	.1584**	.0693**				.6790	3
-.1111					-.6893**	.6332	6
-.2741	.1645**					.6010	3
		Plantation G5					
.1336	.1296**	-.0662**				6410	3
-.1273					-.5466**	.6443	6
-.3092	.1448**					.5979	3
		Plantation G6					
.3080	.1284**	-.0468**				.6113	3
-.0414					-.5964**	.6165	6
-.1317	.1392**					.5385	3
		Plantation G7					
.6238	.0709*	-.0447**		-.7448*		.5882	3
.2535	.1199**	-.0627**				.5696	3
-.2223					-.5455**	.5767	6
-.1521	.1109**					.4716	3

**Significant at .01 probability level.
*Significant at .05 probability level.

stands trees grow independently from other trees. In such open stands the factor I/n will be small even though I and n are rather large. Growth will vary according to the vigor, site, and genetic make-up of the tree. As competition increases, the I/n factor should also increase. Growth should slow in response to the increase in competition and approach zero. It is unlikely that all trees will stop growing at the

Table 6.—Coefficients for predicting 3-year diameter growth and the corresponding coefficients of determination (R^2)

	Independent Variables						
Constant	Initial dbh	Competition index	Competing trees	I/n	ln(I/n)	R^2	Basic equation number
	d	*I*	*n*				
			Plantation G1 (after thinning)				
0.23401	0.13106**	-0.09309**				0.6192	3
-.25801					-0.68599**	.4760	6
-.33144	.14530**					.5069	3
			Plantation G2				
.27232	.17245**	-.14495**		0.78646**		.5438	3
.92609	.10297**	-.15035**				.4961	3
1.59442		-.18467**				.3303	3
.10866	.13170**					.2866	3
			Plantation G3 (after thinning)				
-.18696	.14667**	-.12333**	.02148**	.62075**		.7148	3
-.07586	.16792**	-.04722*				.6807	3
-.30665	.17461**					.6633	3

**Significant at .01 probability level.
*Significant at .05 probability level.

same degree of competition since their vigor depends on a number of factors other than competition. Some trees will die quickly while others might live quite a long time under very severe competition. In other words, the effect of increasing competition on open-grown trees should be quite great, while this effect on trees already experiencing extreme competition might be very slight. The equation finally selected for trial was:

$$G_a = b_0 + b_1 I + b_2 n + b_3 \ln I/n \qquad (6)$$

where: G_a is the diameter growth over a period of a years,
I is the competition index,
n is the number of competing trees,
$\ln I/n$ is the natural log of I/n, and the
b_i's are the partial regression coefficients.

Diameter was not used because of its strong correlation with I/n. The term n was included because it was thought that I/n would then be more meaningful. That is, even if I/n is rather large, the effect on growth might not be great unless n is also quite large. The term I was included for about the same reasons as the term n. Even though I is very large the competition might not be great unless I/n is also rather large. Correlations between these three terms were poor.

The term ln I/n proved to be the best single variable for predicting 2-year diameter growth on four of the seven plantations (G4, G5, G6, and G7) and was nearly as good as initial diameter on plantation G1. On plantation G3 the initial diameter was a much better variable than ln I/n, while neither variable was very good on plantation G2.

Plantations G2 and G3 were both quite open with very low values for I and n. Since competition, as it was measured here, was slight, it could hardly be expected to show a significant effect on growth. Mean values of I, n, d, and G for the 90 samples trees from each plantation are presented in Table 7, while the results of the tests of equation 6 are shown in Tables 5 and 6.

Table 7.—Plantation mean values for the competition index (I), number of competing trees (n), initial dbh (d), and 2-and 3-year diameter growth (basis 90 trees)

	Before thinning			After thinning		Diameter growth	
Plantation	d	I	n	I	n	2 years	3 years
	Inch		*Number*		*Number*	*Inch*	*Inch*
G1	6.85	5.633	22.5	5.027	20.1	.39	.66
Plot 1[1]	6.79	5.295	20.8	3.478	13.6	.49	.85
Plot 2&3[2]	6.87	5.802	23.4			.34	.57
G2	5.00	4.482	16.2			.54	.77
G3	5.46	4.397	16.8	4.100	15.2	.41	.64
Plot 2[1]	5.81	4.176	16.7	3.285	12.0	.49	.79
Plot 1&3[2]	5.28	4.507	16.8			.37	.59
G4	5.56	6.205	20.7			.64	
G5	5.86	5.341	20.2			.54	
G6	5.85	8.050	28.5			.68	
G7	5.87	7.305	29.2			.50	

[1] Thinned plot basis 30 trees.

[2] Unthinned plots of thinned plantation basis 60 trees.

These results suggest that if mean index values are high ($I>5$), and especially if the number of competing trees is high, then the best predictor for diameter growth is simply the natural log of I/n, although the equations using both variables I and d are also good. At any rate, it appears that the index value, I, does measure some of the effect of competition on diameter growth of individual trees. It also seems that the method used in approach 2 for determining the radius of the influence circle is reasonable, or at least it gives an approximate measure of the competition around individual trees.

Growth measurements have been continued for three years on three of the plantations (G1, G2, and G3), so equations 3 and 6 were also tested using this data. Results of this test are presented in Table 6. There was a general improvement in R^2 values when the growth for three years was used. This was not unexpected since individual year-to-year variation should be reduced. Other than this improvement, the results are much the same as for the 2-year growth equations for these plantations. Initial diameter is the best single predictor, and a slight but significant improvement in R^2 is made by adding the index value. Plantation G3 had the lowest average index value and average number of competing trees, and on this plantation significant improvement was obtained by also including the terms n and I/n.

Plantation G2 warrants some special discussion. First, there is a wide variability in number of trees and total basal area among the three plots. Plot 1 is very dense, while the other two are as open as the thinned plots on plantations G1 and G3. The average diameter is also quite different among the three plots. The most unique thing about this plantation is that neither d nor ln I/n was as good as I for predicting growth. In fact, no single variable was really good for predicting growth for this plantation. However, when d and I are both considered, it is possible to account for 15 percent more of the variation in 2-year diameter growth than is possible with I alone, and if I/n is also included an additional 8 percent of this variation can be accounted for.

As a further check the dense plot (plot 1) was analyzed separately from the other two. The trees on this plot were rather small, and so the average index for the 30 sample trees was only 5.588. Diameter was the best single variable on this plot for predicting growth, although the variables I and n were nearly as good for predicting 3-year growth.

It is not clear why the I variable was not significant when used with d to predict growth on this plot. One reason might be that most of these trees are rather small and, as a result, have small influence circles. The maximum circle radius for a sample tree on this plot was 15.6 feet. This tree's circle overlapped the circles of 39 competing trees, but the average competing tree contributed only 0.147 to the index value of 5.736. This sample tree was much larger than the average plot tree and was considerably larger than any of the other sample trees. With so many of the trees being small, it is quite possible that competition between trees had not yet become as important a factor as one might expect.

Another reason that the combination of d and I was not a good predictor of growth might be the condition of the site. The trees on this plot were growing very slowly. The area was heavily grazed by cattle and the soil was very compact. Some of the larger trees were growing quite well, but most of the small trees were hardly growing at all, regardless of their competition index. Of the 30 sample trees in the plot, eight have grown less than 0.1 inch in three years. On the entire plot 60 percent of the trees were less than 4.6 inches at dbh and averaged less than .4 inch in diameter growth in three years. With so many small trees all growing so slowly, it is not surprising that there was no competition apparent. These small trees made so little growth that there was little room for variation, and most of the variation measured was accounted for by diameter alone. In other words, this plot was nearly stagnated, and many of the trees were barely alive. A few large trees were growing well and had been doing so for some time. That is, they had dominated the other trees for several years, and so it was difficult to distinguish the difference between lack of competition and large size. Very few of the dominant trees were in direct competition with each other.

The other two plots in this plantation presented quite a different appearance. They both suffered considerable mortality due to fire and storm. The average index for the 60 sample trees on these plots was only 3.929. However, there was much more variability in diameter and in competition. The correlation between diameter and growth was very poor. Some of the smaller trees were growing well, and it is apparently in such stands that competition was having its most apparent effect.

The best equation for predicting either 2- or 3-year growth on these two plots used both I and n, although I and d were nearly as good. In either case, the variables were highly significant, although at best only 41 percent of the growth variability was accounted for. In such open stands many trees were growing nearly free of competition, and any measure of competition certainly can not account for a large part of the growth variation.

As already noted, when these three plots were combined the factors d, I, and I/n all had a highly significant effect on growth, with I being the strongest single variable. These plots represent extremes at both ends of a density scale (i.e., from very open to very dense), and the fact that the index is a useful tool here would indicate that it should also be useful in more average stands.

One of the objectives of this study was to find some measure of stand density or degree of competition that could be objectively applied to individual trees within a stand. To a degree it appears to me that the competition index I is such a measure. It has been tested with two species at three different ages and on a number of sites and, in most cases, the present index, combined with present diameter, accounted for at least 56 percent of the variation in future growth. In the one case, where only 50 percent of this variation was accounted for, the addition of the index value to the equation of growth over diameter improved the coefficient of determination by some 21 percent.

This index, of course, is still rather crude and certainly does not measure all the factors of competition precisely. In this study, at least, total height and crown radius were estimated by diameter, so that in a given plantation, trees of the same diameter were said to have the same circle radius. Exact measures of every tree, including all competing trees, might result in slightly improved estimates of growth. Exact knowledge of the root systems would also improve the reliability of growth estimates. However, the method described here does offer a method for expressing density and competition for an individual tree.

As noted, the effect of competition in this study does not appear to be very great. However the competition, as measured, was not great either. One would expect competition to be neither as great nor as variable in planted stands as in natural stands where spacing is much less regular. I feel that this measure of competition would prove much more effective in natural stands in which trees tend to be in clumps rather than in regular rows. Certainly the method should be tested in such stands. It is expected that as the value of I increases, the effects of competition will be more apparent.

The Index as a Measure of Thinning

A second objective of this study was to develop a measure of competition that can also be used as an objective measure of thinning intensity. That is, if the competition an individual tree is experiencing could be objectively measured, then the degree of thinning could be measured by determining the reduction in this competition following the thinning. It was with this idea in mind that two plots (plot 1 on plantation G1 and plot 2 on plantation G3) were thinned immediately after they were established. The plot conditions before and after thinning are presented in Tables 4 and 7. It was decided to thin no more plots until the method for measuring competition had been tested.

Since only two plots were thinned, the second objective has not been met. However, it is possible to note changes in index values for the thinned plots. Neither plantation was especially dense, even before thinning. The average index value for the 30 sample trees of plantation G1, plot 1, was reduced from 5.295 to 3.478, while the average number of competing trees was reduced from 21 to 14 as a result of thinning (Table 7). The average index value for the sample trees of plantation G3, plot 2, was reduced from 4.176 to 3.285, while the number of competing trees was reduced from 17 to 12. Competition does not seem to be an important factor affecting diameter growth unless index values are greater than 5.0, so it seems likely that thinning did little more than release trees that needed no release.

In order to note any change in growth pattern after release, it is necessary to know something about the growth pattern of similar unreleased trees growing on similar sites, or at least the growth pattern of those same trees over a previous time period. The two thinned plots were cut at the beginning of the study, so it is not possible to compare their released growth pattern against the previous growth pattern. The thinned plots had been quite similar to the unthinned plots in their respective plantations prior to thinning, so comparisons were made between the growth equation of the single thinned plot and the average growth equation of the two unthinned plots in each of plantations G1 and G3 (Table 8).

Plantation G1

In this plantation the average index value for the 60 sample trees on the unthinned plots (plots 2 and 3) was 5.802, while the average number of competing trees was 23 (Table 7). Thus, while competition was not great on these plots, it was greater than that on plot 1 even before plot 1 was thinned. Thinning reduced the average index on plot 1 considerably below the level where competition becomes a significant factor modifying 2-year growth. Hence, initial diameter showed a

Table 8.—Equations for predicting 2-and 3-year diameter growth on thinned and unthinned plots of plantations G1 and G3

Treatment	Constant	d	I_B[2]	I_A[1]	n_A	I_B-I_A	n_B-n_A	R^2
Plantation G1								
2-year growth								
Thinned	0.5366			-0.0686		-0.1195*	0.0580**	0.5151
Thinned	.5868		-.0925*				.0582**	.4972
Thinned	-.0426	0.0797**						.4323
Not thinned	.1088	.0702**		-.0432*				.5690
Not thinned	-.1952	.0780**						.5254
3-year growth								
Thinned	1.0065			-.1362*		-.2511**	.1078**	.6132
Thinned	1.1197		-.1902**				.1029**	.5844
Thinned	-.2278	.1591**						.5446
Not thinned	-.0680	.1300**		-.0457				.6252
Not thinned	-.3885	.1380**						.6072
Plantation G3								
2-year growth								
Thinned	.0649	.0989**		-.0464				.5438
Thinned	.3866			-.0980*	0.035**			.5475
Thinned	-.1094	.1026**						.5188
Not thinned	.1729			-.0432*	.0232**			.6033
Not thinned	-.1251	.1040**		-.0120				.6123
Not thinned	-.1869	.1054**						.6100
3-year growth								
Thinned	.2072	.1491**		-.0934				.6470
Thinned	-.1434	.1567**						.5971
Not thinned	.2182			-.0630*	.0389**			.6941
Not thinned	-.2647	.1721**		-.0118				.6886
Not thinned	-.3252	.1735**						.6877

**Significant at .01 probability level.
*Significant at .05 probability level.
[1] Subscript A means after thinning.
[2] Subscript B means before thinning.

stronger relationship to growth than any other single variable. However, the before-thinning index plus the change in the number of competing trees due to thinning gave a better equation for predicting growth. These variables were significant factors for predicting both 2- and 3-year growth if initial diameter was not used. On the unthinned plots the combination of the variables d and I gave the best equation for predicting 2-year growth.

All three plots of plantation G1 were burned by wildfire near the end of the second year of the 2-year growth period. Mortality was quite extensive as a result of these fires, and competition was further reduced (Table 2). This was especially true on plot 2, which lost the equivalent of 84 trees per acre or 5 ft² in basal area. Plot 3 lost the equivalent of 32 trees per acre or 7 ft² in basal area. The thinned plot lost very few trees (16 per acre or 1 ft^2 basal area) as a result of these fires.

As a result of these fires competition on plots 2 and 3 was reduced considerably, while it was hardly affected on plot 1. This is reflected in the 3-year growth equations (Table 8). The initial index value was no longer a factor in the diameter growth of the unthinned plots. On the other hand the after-thinning index, the change in the index due to thinning, and the reduction in number of competing trees all were statistically significant in the 3-year diameter growth equation for the thinned plot.

From these results it would appear that the fire reduced competition to a level where it was no longer a significant factor. On the other hand, as trees on the thinned plot continued to grow the competition level increased. It is important to realize that competition is dynamic, increasing or decreasing as trees grow or die. In order to illustrate this change the index values were recalculated, based on the diameter of the surviving trees at the end of the second growing season. The average index for all three plots increased from 5.027 (after thinning) to 5.438. Nearly all of this increase was on the thinned plot, which changed from 3.478 to 4.013 while the index on the unthinned plots only changed from 5.802 to 6.002.

When all three plots are combined, the index value is a highly significant factor of both 2-year and 3-year diameter growth. For this analysis the values after thinning were used. A wide range of sample tree values was available when the three plots were combined. Index values ranged from 1.39 to 9.05, diameter ranged from 2.6 to 12.7 inches, and competing trees ranged from 7 to 61 per sample tree. Growth per sample tree also covered a wide range. The 3-year growth, for example, ranged from 0.01 to 1.79 inches; yet some 62 percent of this variation could be explained as variations in initial diameter and in competition.

Plantation G3

This plantation did not appear to be as open as plantation G1. The average basal area (92 ft^2 per acre) was rather high. However, the trees were well spaced and there were openings, due to hurricanes, scattered throughout. As a result, the average index for the sample trees on these plots was only 4.397 (ranged from 1.22 to 7.88) even before plot 2 was thinned. The average competition for these trees was lower, even before thinning, than the average competition for any other plantation. The variance for the index was also low on this plantation.

Thinning reduced the average index of the thinned plot from 4.176 to 3.285, and the overall average for the plantation to 4.100. The two unthinned plots had an index average of 4.507. Competition does not appear to be a great factor in the growth on this plantation, and was certainly not a significant variable in the 2-year growth equation, unless it was included with diameter, number of competing trees, and the average index per competing tree (I/n). The best single variable for predicting 2-year growth was the initial diameter, which alone accounted for some 58 percent of the growth variation. When the variables I, n, and I/n were also included, only 62 percent was accounted for (Table 5).

Competition was not a significant factor affecting either 2-year or 3-year diameter growth on the thinned plot. Neither was it significant on the unthinned plot when included with diameter. On these plots the number of competing trees combined with the index gave a good estimate of both 2- and 3-year growth. However, diameter alone was just as good. It appears from these results that there was little gain in individual tree diameter growth on this plantation as a result of thinning.

The best 3-year growth equation, when thinned and unthinned plots were combined, was the one that considered the four variables, d, I, n, and I/n, just as for the 2-year growth equation. However, the I variable was significant when combined with d alone. Competition is apparently becoming a factor in this plantation. Average competition index values increased on both the thinned and unthinned plots, so that by the end of the second year of the growth period the overall average index increased from 4.100 to 5.018.

Discussion

The purpose of this study was to measure intraspecific competition and to study the effects of this competition on the diameter growth of a tree. Such diameter growth can be affected by a large number of factors other than competition. An attempt was made to control as many of these other factors as possible. Variations in diameter growth due to species, climate, and soil variation were controlled to some extent by limiting the number of species studied to two, by locating the entire study within a relatively small area (130 sq. miles), and by comparing only those differences among trees within a single plantation.

Some factors could not be controlled. For example, the genetic composition of these trees was not known. Variations due to micro-site differences within a single plot were not controlled, except as these differences had affected past growth (i.e., variations in initial diameter are probably the result of differences in genetic composition, micro-site, and past competition).

It is generally believed that much of the variation in diameter growth among trees within an even-aged stand is the result of competition. But competition comes from many sources. Other trees of the same or different species, brush, vines, grass and all other vegetation are possible sources of competition. The purpose of this study was to study and measure only the single source, intraspecific competition. Plantations were selected rather than natural stands in order to eliminate variation due to differences in age, but also to eliminate other species of trees as sources of competition. All vegetation had been removed from these plantation areas prior to planting. Frequent fires (both wild and prescribed) had kept hardwood sprouts and brush to a minimum. Grass and brush are known to be significant sources of competition to trees, especially young trees (Curtis, 1964; Larson and Schubert, 1969). On the plantations in this study, however, there is not a great deal of difference in the grass cover between plots within the same plantation. It is believed that little of the variation in current tree diameter growth results from variation in grass or brush cover.

The method used for measuring intraspecific competition involves assigning a circular area to each tree and then determining how much of this area is occupied by the areas of other trees. In theory, the more a tree's area is occupied by the areas of other trees, the less will be the diameter growth it makes. Variation in diameter growth that can not be explained in this way is, in theory, due to the variations in some of the other known factors affecting diameter growth, or else it is due to random error.

The index described above is not a precise measure of intraspecific competition. It is doubtful if every tree influences an area that is exactly circular, and it is very doubtful if the radius of such an area is exactly proportional to hc/m. However, this index does seem to give a good approximation of competition in that it is a significant variable in equations for predicting individual tree growth.

The influence circle is meant to be an expression of total space available to a tree, including its crown and its roots. It is relatively easy to determine the area occupied by a tree's crown but very difficult to determine the area of its roots. It seems likely that the roots extend some distance beyond the extent of the limbs, so that the influence circle should have a radius greater than the average radius of the tree's crown. If this is so, then it is likely that trees not adjacent to the sample tree can still be competing with the sample tree.

An early study of the effect of competition on growth of individual southern pine trees was carried out by MacKinney (1933). He noted the number and size of competing trees in 10-foot zones out to 30 feet from his sample trees and discovered that competing trees in the outer zones had more effect on basal-area growth of sample trees than those adjacent (within 10 feet) to the sample trees.

More recent studies have given new insight into the horizontal distance tree roots extend. Kaufman (1968) has reported that slash pine can, under certain conditions, extend their roots as much as 56 inches per year during the first 3 years after planting. Pritchett and Robertson (1960) noted that 5-year-old slash pine absorbed nutrients from as far away as 32 feet from the base of the trunk. Hough *et al.* (1965) introduced I-131 into the soil and detected radioactivity in trees as far as 55.1 feet from the point of the treatment. This distance was related to the age of the tree. It is clear from these and other studies (see also Curtis, 1964; Ferrill and Woods, 1966) that roots are likely to extend some distance beyond the maximum extent of the crown.

The maximum sample-tree radius in the present study was 46 feet. However, most trees had a much smaller radius than this. Judging from the results of studies concerning root extension, this maximum radius might not be too great since this was for a tree whose diameter was over 12 inches. Nevertheless, the method for determining this radius is only an approximation that requires the assumption that the total influence circle is directly related to certain measures of the above-ground portion of the tree. The only proof available that this is true is the fact that diameter growth was significantly affected by competition as measured according to these assumptions.

Only a small portion of the variability in growth was accounted for by the index if initial diameter was also included. This could be either because competition was not measured correctly or because there was little competition to measure. Young planted stands generally exhibit less evidence of competition than do natural stands. In plantations the minimum space between trees is set by planting distance and, since there is generally some mortality each year, by age 15 the average spacing is much greater than this minimum. Also, there is often less variation in diameter within planted stands. It therefore seems likely that in many of the plantations of this study there was little competition to measure. Actually, in those plantations where the average index for the sample trees was 5.3 or greater, the best variable for predicting growth was the natural log of I/n. This would seem to indicate that if competition is a strong factor, then the combination of I and n is a reasonably good measure of this competition and is a useful measure for predicting growth regardless of the tree's initial diameter.

One advantage of this method is that it can be used to express density and also changes in density due to mortality or thinning. Various tree parameters, such as diameter or crown radius, can be used to predict growth. However, these parameters show no immediate change if thinning is done. The index and the number of competing trees both change according to the degree of thinning and therefore may be used as measures of density and thinning intensity. An added advantage to this index method is that a measure of the variation in the competition index can be computed so that statistical comparisons can be made between the mean indices of several stands. Preliminary tests have indicated that the distribution of competition indices in a stand does not differ significantly from a normal distribution; therefore, standard statistical tests may be used for such comparisons (Keister, 1966).

This competition-index method considers the actual spacing of the trees rather than assuming an even or regular spacing. It also requires consideration of the relative sizes of the various individual trees. Finally, the method makes possible the use of individual trees rather than plots for thinning and growth studies.

The most serious disadvantage of this competition index is the large number of field measurements necessary for its computation. The heights, crown lengths, crown radii, and diameters of a number of trees must be measured so that curves of total height and crown radius can be computed, and so that the average dead-limb length can be determined. In addition, the diameters of all possible competing trees surrounding a particular sample tree must be measured and the horizontal distance between trees must be determined.

In general, however, the advantages of being able to use individual trees rather than plots in thinning and growth studies should offset the disadvantage of the rather cumbersome field work. I believe that the competition index described here shows promise as a useful tool in thinning research and growth studies, and may also find use in stand simulation for management purposes.

Summary

A method is presented for measuring the intraspecific competition experienced by an individual tree in a planted stand. It is theorized that each tree in the stand interacts within a circular area surrounding the tree, that the size of this area is proportional to the size of the tree, and that intraspecific competition occurs in proportion to the area within the zone where two or more of these circles overlap.

A competition index for a particular tree is expressed as the ratio of the sum of the areas of overlap within the particular tree's influence circle to the total area of the tree's influence circle. That is, if area of overlap between the k th tree and the i th tree is C_{ik} then the competition experienced by the k th tree from the i th tree is defined as:

$$I_{ik} = C_{ik}/\pi K_k^2$$

where K is the radius of the k th tree's circle. The total competition index for the k th tree is defined as:

$$\sum_{i=1}^{n} I_{ik} = (1/\pi K_k^2) \quad \sum_{i=1}^{n} C_{ik}$$

Two approaches were tried for determining the radius of a tree's influence circle. In the first approach this radius was set equal to Zh, where h is the total height of the tree and Z is a factor that should be constant for a given species, site, and age. This approach was tested in the field and finally discarded since Z could only be determined empirically for a given stand and no method was found for predicting the proper value of Z from existing stand conditions.

The second approach was to set the radius equal to a combination of three measurable tree and stand parameters. The radius was set equal to hc/m, where h and c are total height and crown radius, respectively, and m is the dead-limb length. The height and crown radius are both related to diameter, while in the plantations used in this study the dead-limb length is quite constant and is thought to be an expression of age, site, and total stand density.

This method for measuring competition was tested in four 15-year-old and one 14-year-old slash-pine plantation, one 11-year-old loblolly-pine plantation, and one 14-year-old mixed slash- and loblolly-pine plantation. These plantations were growing on several different sites in Livingston Parish, in southeastern Louisiana, and included a wide range of conditions.

The first objective was to see if the index could be used to predict diameter growth since diameter growth is thought to be modified by competition. Three ¼-acre plots were located in each plantation, and 30 trees were selected as sample trees on each plot. The diameter, height, crown radius, and dead-limb length of every tree on each plot were measured. The position in relation to the plot center was determined for every tree, and stand maps were prepared.

The index values for each sample tree were computed at the start of the study, and diameter growth was measured for two years in all plantations and for three years in three of the 15-year-old slash-pine plantations.

The initial tree diameter was the best single variable for predicting diameter growth in most plantations, and about 50 percent of the variation in growth could be accounted for by this variable alone. The addition of the index value to diameter accounted for a slight but statistically significant improvement in the growth equations for all but one of the seven plantations studied.

In plantations that had average index values higher than 5.1 or that had a wide range of indices, the best variable for predicting growth was the natural log of I/n, where I is the competition index value for a particular sample tree and n is the number of competing trees (i.e., trees whose circles of influence overlap the circle of the sample tree). This single variable was as good as or even better than the equation that used initial diameter and the index. Plantations that were more open (i.e., average indices <5.1) did not show this relationship, probably because most sample trees on such plots had indices that were rather low. The best equation, then, for predicting growth in open plantations was:

$$G = b_0 + b_1 d + b_2 I$$

while if the plantation was more dense the best equation was:

$$G = b_0 + b_1 \ln(I/n)$$

where G is the diameter growth over a 2- or 3-year period,
d is the dbh at the start of the growth period,
I is the competition index at the start of the growth period,
n is the number of competing trees, and the
b_i's are the partial regression coefficients.

These results indicated that this measure of competition was valid.

A second objective of this study was to see if the index could be used as an objective measure of thinning intensity. One plot from each of two of the oldest slash-pine plantations was thinned before the start of the initial growing season. No other thinning has been done at this time, so this objective has not really been met. The thinned plantations were not very dense, even before thinning, so the reduction in competition apparently had no great effect on the growth of the sample trees. One plot had an average index of 5.295 before thinning while the other had an average index of only 4.176. The after-thinning average index on these plots was, respectively 3.478 and 3.285. Competition was not a significant factor on either plot during the first two growing seasons. The 3-year growth on the plot originally having an I of 5.295 was significantly affected by competition. Over 60 percent of the variation in 3-year growth on this plot was accounted for by the equation:

$$G = 1.0065 - .1363\ I_A - .2511\ I_D + .1078\ n_D$$

where I_A is the after-thinning index, I_D is the difference in the before- and after-thinning indices, and n_D is the change in the number of competing trees due to thinning. In the other plot competition has not been a strong factor.

These results were not conclusive but do indicate that the index might be used to measure the release from competition obtained by thinning. This study is being continued.

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ffects of Zinc and Other Elements On the Yield of Rice and lutrient Content of Rice Plants

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COVER PICTURE

The picture on the cover shows the effect of zinc on the growth of rice on Crowley silt loam, pH 7.4. The soil in this field had previously been water leveled. Yields are shown in Table 2, Page 5.

Effects of Zinc and Other Elements On the Yield of Rice And Nutrient Content of Rice Plants

J. E. SEDBERRY, JR., F. J. PETERSON, EMMETT WILSON,
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Zinc investigations in Louisiana have primarily involved research conducted under field conditions to determine the effects of zinc and other micro and secondary nutrients on the yield and chemical composition of the rice plant. Investigations with zinc and rates of limestone and zinc and rates and sources of phosphorus are currently being conducted.

Rice is produced under conditions that are quite different from those of many other crops grown in the Southern Region. It is produced primarily on Prairie soils under submerged conditions. After submergence, reducing conditions develop and as a general rule the solubility of phosphorus, manganese, and iron compounds present in the soil increases. Frequently, flooding results in a 20% increase in extractable phosphorus on soils that are considered to be relatively low in phosphorus. Flooding an acid Prairie soil also results in an increase in soil pH. It is not uncommon for the pH of a Crowley soil to increase from about 5.5 to 6.5 or higher after submergence for a period of six weeks. Unfortunately, data are not yet available on the effect of submergence on the solubility of zinc. However, preliminary investigations indicate that flooding a Crowley soil for a period of eight weeks significantly increases zinc that can be extracted from the soil with 0.1 normal hydrochloric acid.

Another management practice that is in use by rice farmers that may have a pronounced effect on the solubility of zinc and other nutrients is "water-leveling." In many instances a large quantity of soil is moved in water leveling and subsoils are exposed that are deficient in "available" forms of certain plant nutrients. Responses to zinc have been obtained on soils that have been water leveled, and large yield increases have been obtained on soils that were severely cut.

In 1966 an experiment was initiated on Crowley silt loam to determine the effects of phosphorus, zinc, sulphur, iron, and copper on the yield of Saturn rice. The results of this experiment conducted for a

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Table 1.—The effects of phosphorus, zinc, sulphur, iron, and copper on the yield of Saturn rice grown on Crowley silt loam[1] (The Raymond Leonards farm, Acadia Parish, Louisiana, 1966-1968)

Micronutrient applied[2]	Yield of rice, average of three replications			
	No phosphorus		22 lbs. P per acre	
	3-Yr. avg.	Increase	3-Yr. avg.	Increase
	pounds of rice per acre, 12% moisture			
Check	2,719	---	2,758	----
Zinc	3,467	748	3,676	918
Sulphur	3,432	713	3,462	704
Iron	3,081	362	2,881	123
Copper	2,771	52	2,624	—134
Zn, S, Fe, Cu	3,547	828	3,937	1,179
Average	3,159		3,222	

There were no significant differences among phosphorus treatments. The differences in yield among micronutrient treatments were highly significant.

[1] Initially, the soil contained 0.40 ppm of dilute acid-extractable Zn, 18 ppm P, 42 ppm K, 1,170 ppm Ca, and 328 ppm Mg. The pH was 7.4.

[2] Zinc was applied as zinc chelate, 14.2% Zn, at a rate equivalent to 6 pounds of the chelate per acre. Sulphur was applied as elemental sulphur, 99.6%, at a rate equivalent to 1,000 pounds per acre. Iron was applied as iron chelate, 12% Fe, at a rate equivalent to 20 pounds of the chelate per acre. Copper was applied as copper chelate, 13% Cu, at a rate equivalent to 5 pounds of the chelate per acre.

three-year period are shown in Table 1. The data indicate that phosphorus applied with or without micronutrients had no significant effect on yield. Initially, the untreated soil contained 18 ppm of dilute acid-extractable phosphorus. Zinc and sulphur applied singly and in combination with iron and copper had the greatest effect on increasing the yields of rice. The zinc content of the soil was 0.40 ppm. The application of sulphur reduced the soil reaction from pH 7.4 to 6.5. In 1967 and 1968, the application of copper alone resulted in a yield reduction both with and without added phosphorus. This reduction in yield may have been due to toxicity from copper from repeated applications the second and third year.

There was less frequent occurrence of "bronzed" rice plants growing on plots receiving zinc or sulphur or combinations of these nutrients. The application of iron or copper alone had no effect on the incidence of "bronzed" plants.

The effects of soil reaction and application of zinc on the yield of rice grown on Crowley silt loam are presented in Table 2. Adjusting the soil reaction from pH 6.9 to pH 7.4 where zinc was not applied resulted in a yield depression of approximately 1,300 pounds of rice per acre. A further reduction of 1,121 pounds was obtained when the pH was increased from 7.4 to 7.8. The application of zinc resulted in significant yield increases at each level of soil pH. Increased yields attributed to the application of zinc were 1,089 pounds of rice per acre at pH 6.9, 1,615

Table 2.—The effects of soil reaction and application of zinc on the yield of Saturn rice grown on Crowley silt loam (Rice Experiment Station, Crowley, Louisiana, 1968-1970)

Soil reaction	No zinc (3-Yr. avg.)	Zinc[1] (3-Yr. avg.)	Increase from zinc
pH	pounds of rice per acre, 12% moisture		
6.9	3,533	4,622	1,089[2]
7.4	2,209	3,824	1,615
7.8	1,088	3,824	2,736
Average	2,277	4,090	1,813

[1] Zinc was applied at a rate of 12 pounds of Na_2Zn, 14.2% Zn, per acre.
[2] The differences were significant at the 5% level of probability.

pounds at pH 7.4, and 2,736 pounds at pH 7.8. Even though the application of zinc resulted in relatively large increases in yields on soils with pH values of 7.4 and 7.8, the yields were significantly lower than those obtained on soils at pH 6.9. This indicated that zinc and possibly other micronutrient elements were immobilized at the higher pH levels.

The effects of soil reaction and application of zinc on the zinc content of rice tissue are presented in Table 3. The application of zinc to the soil at all pH levels increased the zinc content of the rice tissue. Consistently lower values for zinc were obtained when the tissue was dry ashed in a muffle furnace as opposed to acid digestion. Dry ashing of plant material invariably leaves a residue of silica which adsorbs traces of micronutrients. This is particularly true of rice tissue which is relatively high in silica, and losses of zinc by adsorption on silica may be as high as 25 per cent or more unless the silica is removed by treatment with hydrofluoric acid.

Table 3.—The effects of soil reaction and application of zinc on the zinc content of the plant tissue of rice grown on Crowley silt loam (The Rice Experiment Station, Crowley, Louisiana, 1968)

Soil reaction	Method of analysis	Zinc treatments	
		No zinc	Zinc[1]
pH		Zinc content —parts per million—	
6.9	dry ashed	9.0[2]	12.0[2]
	wet ashed	15.4	18.9
7.4	dry ashed	8.1	10.0
	wet ashed	14.0	17.1
7.8	dry ashed	7.7	9.6
	wet ashed	15.0	17.5

[1] Zn was applied at a rate of 12 pounds of Na_2Zn, 14.2% Zn, per acre.
[2] Entire rice plant was sampled when panicle was 2 mm. long.

The effects of five rates of zinc on the yield of rice and the residual zinc content of Crowley silt loam after two annual applications of zinc are presented in Table 4. The application of zinc did not significantly increase the yield of rice. However, in 1969 and 1970 the yields on plots that received zinc were consistently higher than were those on check plots. After harvest in 1969, increases in soil zinc were detected at each rate of applied zinc. Relatively large increases, 3.4 and 8.9 ppm, in the zinc content of the soil were measured following two annual applications of 12 and 24 pounds of zinc per acre. No adverse effects on the milling quality of rice have resulted from the rates of zinc used in this investigation. Research is currently underway to determine the effects of high rates and different sources of zinc on the zinc content of both rough and milled rice.

Table 4.—The effects of five rates of zinc on the yield of rice and the residual zinc content of Crowley silt loam,[1] 1968-1970

Zinc treat-ments[2]	Yield, avg. of 4 replications			Zn content of soil	
	1968	1969	1970[3]	1969[4]	Increase over check
lbs./A.	——lbs./A., 12% moisture——			—parts per million—	
0	5,980	3,036	3,303	1.4	---
3	5,970	3,536	3,961	2.0	0.6
6	5,970	3,424	4,365	3.2	1.8
12	6,010	3,484	4,271	4.8	3.4
24	5,890	3,390	4,503	10.3	8.9

The differences in yield were not significant in 1968, 1969, or 1970.

[1] Initially the soil contained 1.2 ppm of Zn and the pH was 7.0.

[2] The source of zinc was $ZnSO_4.H_2O$, 36% Zn.

[3] Zinc was not applied in 1970.

[4] The zinc analysis was made after applications of zinc in 1968 and 1969.

The effects of five rates of zinc on the nutrient content of rice leaves are presented in Table 5. A small but consistent increase in the Zn con-

Table 5.—The effects of five rates of zinc on the nutrient content of the leaves of Saturn rice grown on Crowley silt loam, 1969

Zinc treatments[1]	Nutrient content of rice leaves, avg. of 2 reps.[2]				
	Zn	Mn	Fe	Na	N
lbs./A.	——parts per million——				%
0	22	820	287	910	1.44
3	23	461	146	488	1.91
6	27	336	119	445	2.10
12	28	492	136	540	1.70
24	32	288	112	613	2.49

[1] Zinc sulphate, 36% Zn, was the source of zinc.

[2] Plants were sampled when the panicle was 2 mm. long.

tent of rice leaves was obtained with each rate of applied zinc. The highest concentration of zinc in the leaf tissue was obtained on plants from plots that received zinc at the rate of 24 pounds per acre. The application of zinc caused a pronounced reduction in the manganese, iron, and sodium concentration in the leaves. The zinc treatments resulted in increases in the nitrogen content of the leaves. The leaves of rice plants growing on plots that received the highest rate of zinc produced chlorotic symptoms that were thought to be iron deficiency. The data suggest that high rates of zinc are antagonistic to manganese and iron and that applied zinc may induce iron deficiency on soils that are neutral to alkaline in reaction.

The effects of different sources of zinc on the yield of rice and the residual zinc content of Crowley silt loam after two annual applications are presented in Table 6. The zinc treatments had no significant effect on yield of rice in 1968 and 1969. In 1970 the application of zinc as zinc chloride, zinc chelate, zinc sulphate, and zinc oxide resulted in significant increases in yield. Although the differences obtained from the various sources of zinc were not significant, the highest yields were obtained on plots that received zinc oxide. The application of zinc chloride, zinc sulphate, and zinc oxide resulted in the largest increases in the zinc content of the soil. The zinc chelate application resulted in the smallest increase in residual soil zinc.

Table 6.—The effects of different sources of zinc on the yield of rice and the residual zinc content of Crowley silt loam,[1] 1968-1970

Source of zinc[2]	Yield, avg. of 4 reps. 1968	1969	1970	Zn content of soil 1969[3]	Increase over check
	—pounds per acre, 12% moisture—			—parts per million—	
Check	5,550	2,599	2,541	1.3	---
Zinc chloride	5,770	3,049	4,549*	2.8	1.5
Zinc chelate	5,670	2,916	4,489*	1.7	0.4
Zinc sulphate	5,560	2,949	4,617*	3.1	1.8
Zinc oxide	5,500	2,826	4,887*	2.9	1.6
LSD at 5%	NS	NS	1,104		

[1] Initially the soil contained 1.2 ppm of zinc. The pH was 6.9.

[2] The inorganic sources of zinc were applied at a rate equivalent to 6 pounds of Zn per acre. Zinc chelate was applied at a rate of 1.7 pounds of Zn per acre.

[3] The zinc analysis was made after applications of zinc in 1968 and 1969.

*The differences in yield were significant at the 5% level of probability.

The data in Table 7 indicate that the application of all sources of zinc increased the zinc concentration in the rice leaves and significantly reduced the manganese, iron, and sodium contents. The application of all of the zinc sources resulted in increases in the total nitrogen content of the leaf tissue.

Table 7.—The effects of different sources of zinc on the nutrient content of the leaves of Saturn rice grown on Crowley silt loam, 1969

Source of zinc[1]	Nutrient content of rice leaves, avg. 2 reps.[2] Zn	Mn	Fe	Na	N
	parts per million				%
Check	17	639	200	911	1.65
Zinc chloride	27	371	115	650	2.10
Zinc chelate	22	392	112	565	2.12
Zinc sulphate	27	270	108	600	2.84
Zinc oxide	25	289	106	430	2.49

[1] The inorganic sources of zinc were applied at a rate equivalent to 6 pounds of Zn per acre. Zinc chelate was applied at a rate of 1.7 pounds per acre.

[2] Plants were sampled when the panicle was 2 mm. long.

Zinc deficiency in rice grown on Prairie soils in Louisiana frequently occurs when the zinc content of the soil, determined by extracting the soil with 0.1 normal hydrochloric acid, is about 1.2 ppm or below. A yield response to applied zinc may be obtained when the concentration of zinc in the leaves of rice is less than 15 ppm.

Suggestions for the Correction of Zinc Deficiency of Rice Grown on Prairie Soils

Rice growing on soil that has exhibited symptoms of zinc deficiency (bronzing of plants) should receive an application of zinc supplied as granular zinc sulphate, 36% Zn, or powdered zinc chelate, 14.2% Zn, or liquid zinc chelate, 6% Zn.

It is suggested that the grower apply zinc sulphate at a rate equivalent to 7.2 pounds of metallic zinc per acre or zinc chelate at a rate equivalent to 0.85 pound of metallic zinc per acre to the soil prior to or at the time of seeding rice. The zinc materials may be applied directly to the soil or they may be blended with the mixed fertilizer.

In the event that bronzing occurs on a soil that was not suspected to be deficient in Zn, a foliar application of the chelate from either a solid or a liqud source should be made as early as possible after symptoms appear. It is suggested that an application of zinc chelate at a rate of 0.42 pound of metallic zinc per acre be made.

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The Effects of Combinations of Lime and Fertilizers on Yields Of Cotton, Corn, and Hairy Vetch

B. E. Newman[1]

Introduction

The Agricultural Stabilization and Conservation Service of the United States Department of Agriculture estimated that less than 300,000 tons of lime were used on Louisiana croplands in 1967. It has also been estimated that this is only one-third of the lime needed annually for optimum agricultural production in Louisiana.

The adjustment of soil reaction to the proper level is important in good soil management. This must be done if maximum production and profits from the use of fertilizers are to be obtained.

There are many benefits derived from the use of lime other than the neutralization of soil acidity. In addition to supplying two secondary plant nutrients, calcium and magnesium, lime influences the solubility of certain compounds of iron, aluminum, manganese, and many other elements. Some compounds come into solution in strongly acid soils and "lock-up" both native and applied phosphorus, making it less available to the plant. High levels of aluminum and manganese are known to be toxic to some crops. Lime renders these elements less soluble and, as a result, less harmful to the crop. Lime also affects the utilization of nitrogen and potassium.

The frequency with which lime should be applied depends on many factors and can best be determined by soil analysis. Excessive use of lime should be avoided. Too much lime may reduce the availability of iron, phosphorus, manganese, boron, copper, and zinc, and may also suppress the availability of potassium. A well-balanced fertilization and liming program is essential in a successful farming operation.

Review of Literature

Most soil scientists agree that use of the word "lime" refers to any material high in calcium or which corrects certain physiological conditions when applied to a moderately- or strongly-acid soil. Bear (*4*)[2] stated that the elements calcium and magnesium have other functions in the soil and plant than those of simply neutralizing soil acid. He also stated that if the soil is deficient in magnesium, then a limestone product high in magnesium, such as dolomitic limestone, is to be preferred over one that is high in calcium.

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[1] Department of Agronomy.

[2] Italic numbers in parentheses refer to Literature Cited, page 13.

Russell (*28*) stated that the secondary effects of high acidity or low pH in a soil are shortage of available calcium and sometimes phosphate on the one hand, and an excess of soluble aluminum, manganese, and perhaps other metallic ions on the other. He also stated that these harmful effects of soil acidity can always be corrected by the judicious use of calcium carbonate, which raises the pH and the level of available calcium and lowers that of manganese and aluminum.

Bender and Eisenmenger (*5*) have shown that the calcium content of certain plants varies with the calcium saturation of the soil, and Batholomew (*3*) has obtained evidence indicating that soluble magnesium salts increase the absorption of phosphates. Magnesium may also play an important role in the translocation of phosphorus in plants (*24, 32*). Magnesium may be applied to the soils in a number of materials (*7, 14*), the principal one being dolomitic limestone.

Newman and Brupbacher (*20*) reported that acidic carriers of nitrogen supplemented with dolomitic limestone produced significantly higher yields of seed cotton than did acidic carriers of nitrogen without lime. They also reported that the extractable manganese content of the soil was less from plots that had received an acidic carrier of nitrogen supplemented with lime than from those receiving a similar source of nitrogen without lime.

Crinkle leaf, a disorder of cotton occurring on very acid soils, was first described by Neal (*18*), working on cotton diseases in Louisiana in 1937. The work of Neal and Lovett (*19*) on Memphis (formerly Lintonia) and Olivier silt loam soils in Louisiana in 1938 indicated that excessive manganese caused crinkle leaf in cotton and that this disorder could be eliminated with lime by increasing the pH of the soil. Adams and Wear (*1*), in Alabama, concluded that crinkle leaf in cotton could be expected as sufficient acidity developed in soils that have a potential for supplying soluble manganese, and that the necessary preventive measure for crinkle leaf in the field was adequate liming.

The quantity of lime to apply and the frequency of applications can best be determined through soil analysis. White and Gardner (*34*) screened limestone into grades and tested its effect in correcting soil acidity. They reported that limestone dust passing a 100-mesh screen and applied to a particular soil produced an alkaline reaction the first year, but by the end of the third year the soil again showed slight acidity. Liming material passing a 60-mesh screen did not produce an alkaline reaction until the second year, the 20-mesh material did not produce a reaction until the end of the third year, and soil to which 8-mesh material was applied still showed a lime requirement of 3,000 pounds per acre at the end of three years.

Much experimental data are available on the benefits of liming and the influence of soil reaction on nutrient availability (*33*). Bear (*4*) reported that nitrification processes in the soil are speeded up by applying liming materials. It has also been reported that liming acid soils has a beneficial effect on the utilization of both applied and native phosphorus (*26*). Salter and Barnes (*29*) showed that by maintaining the soil reaction at about pH 7.5, satisfactory crop yields could be produced with minimum investments in phosphate fertilizer. Singh and Seatz (*30*) reported that phosphorus applied after liming an acid soil was more available to plants than when the phosphorus was applied to the soil three months prior to liming. Robertson, et al (*27*), concluded that phosphorus interacted with lime and less phosphorus was necessary to give maximum yields on limed soil than on unlimed soil.

Paden and Riley (*21*) reported higher increases in yield of seed cotton per pound of potassium applied on limed soil than on unlimed soil. Thorp and Hobbs (*31*) reported that potassium uptake by alfalfa was significantly increased by lime applications. Pearson (*23*) made an intensive review of the research on the influence of liming on potassium availability and stated that in spite of the fact that liming frequently decreased the solubility of soil potassium, the ultimate effect of liming on the utilization of fertilizer potassium had been found to be highly beneficial.

Russell (*28*) stated that large dressings of lime may induce magnesium or potassium deficiencies in crops. He explained this phenomenon as ionic antagonism—increasing the relative concentration of any one cation in the soil, as for example, calcium or magnesium as a result of liming, reduced the potassium uptake by the plant because of competition or the antagonistic effects among the cations. Calcium may also be a factor in precipitating soluble phosphorus. It has been reported that when the soil pH gets above 7.0, insoluble calcium phosphates appear (*13, 15*). Thus, excessive liming may precipitate water-soluble phosphorus compounds into forms that are only partially available.

Pierre and Browning (*25*) reported that injury to crops from overliming in West Virginia was due to disturbed phosphate nutrition.

The effects of overliming on the availability of certain micronutrients have been reported (*8, 33*). Too much lime reduces the availability of iron, manganese, boron, copper, and zinc. It is important to recognize the dangers of indiscriminate use of lime (*16, 17*) and the failure to follow a well-balanced fertilizer and lime program.

It has been widely demonstrated that crop yields and certain physical properties of the soil can be improved through use of winter legumes as a green manure crop (*9, 10, 11, 22, 35*).

Davis, Hobgood and Brewer (*10*), in Louisiana, reported that the green weight of hairy vetch (*Vicia villosa*) was increased 2.9 tons per acre in St. Landry Parish and 2.1 tons per acre in Natchitoches Parish with the application of 500 pounds per acre of basic slag. They also reported the effects of phosphorus on the yield of vetch. The green weight of vetch was 4.3 tons per acre with the application of 225 pounds per acre of 18 percent superphosphate as compared with only 2.2 tons per acre where no superphosphate was applied.

Bailey, Williamson and Duggar (*2*) reported that the yield of hairy vetch in Alabama was increased with the application of superphosphate. The green weight of vetch with no fertilizer was 1,589 pounds per acre as compared with 8,874 pounds per acre with the application of 400 pounds per acre of superphosphate.

Harper (*12*), in Oklahoma, reported the residual effects of fertilizers applied to cotton with and without lime on the yield of hairy vetch and other winter legumes. On the unlimed soil, the 15-year average yield of dry vetch was 862 pounds per acre where no fertilizer was applied to the cotton as compared with 1,456 pounds per acre where 40 pounds per acre of P_20_5 were applied to the cotton annually. When an equal amount of P_20_5 plus 60 pounds per acre of K_20 were applied to the cotton, the yields of dry vetch were 1,514 and 1,621 pounds per acre for the unlimed and limed soil, respectively.

Experimental Procedures

An experiment was initiated in 1955 on the Perkins Road Agronomy Research Farm at Baton Rouge. The soil on which the experiment was located was classified as Richland (later changed to Loring) silt loam. A composite sample of the surface soil was taken from the experimental area for chemical analyses. The extractable phosphorus, potassium, calcium, and magnesium were determined. A sample of the soil was extracted with a 0.05 normal nitric acid solution using a soil-to-extraction solution ratio of 1:20. The amounts of potassium and calcium in the extract were determined using a Perkin-Elmer Model 52C flame photometer. The concentration of magnesium in the extract was determined by the Clayton yellow colorimetric method. The concentration of phosphorus in the soil was determined from an aliquot of the soil extract after a color had been developed by adding a solution containing ammonium molybdate, sulphuric acid, and an acidified solution containing stannous chloride. The intensity of the color developed was measured using a Fisher electrophotometer.

Soil reaction (pH) and lime requirement were determined according to procedures described in Louisiana Agricultural Experiment Station Bulletin No. 632 (*6*). The extractable nutrients in the soil were as follows: 15 ppm of P, 42 ppm of K, 391 ppm of Ca, and 92 ppm of Mg. The pH of the soil was 5.6. It was determined that 3,000 pounds per acre of $CaC0_3$ would be necessary to obtain a pH value of 6.5 to 7.0.

The chemical and screen analyses of liming materials used in the experiment were as follows:

Chemical Analysis

	Dolomitic Limestone	Oyster shell flour
	%	%
$CaCO_3$	50.0	97.0
$MgCO_3$	40.0	—
Neutralizing power	97.4	97.0

Screen Analysis

	Dolomitic limestone	Oyster shell flour
	%	%
20-mesh	100	100
200-mesh	70	70

The fertilizer materials used in the experiment were ammonium nitrate (33.5 percent N), ordinary superphosphate (20 percent available P_20_5) and muriate of potash (60 percent K_20).

Cotton varieties used in the experiment were Deltapine 15 for 1955, 1956, and 1958; Stardell for 1959, 1960, and 1961; Deltapine Smoothleaf for 1963, 1965, and 1966. Corn hybrids used were Dixie 18 for 1957, 1962, and 1964, and Funks G-795W-1 for 1967.

Hairy vetch was planted each year immediately after harvesting the cotton or corn and the vetch green manure was turned under in the spring approximately three weeks before planting cotton or corn. Yield data from nine crops of cotton, four crops of corn and three crops of vetch were obtained.

A split-plot design with three replications was employed. One of the three main plots was treated with dolomitic limestone, one with oyster shell flour, and one received no lime. The main plots were subdivided into eight subplots, each consisting of six 42-inch rows 90 feet long. Fertilizer mixtures in which N, P_20_5 and K_20 were combined at three different levels (0, 32, and 64 pounds per acre) were applied to the subplots annually. The liming materials were applied broadcast at the rate of 3,000 pounds per acre each and thoroughly disked into the soil approximately three months prior to planting of the first crop of cotton in 1955. No additional lime was applied throughout the duration of the experiment.

Yield data for cotton and corn were taken from the two inside rows of each subplot. Vetch yields were taken from the second and fifth rows of each subplot.

Results and Discussion

The effects of sources of lime and of no lime in combination with various fertilizer mixtures on the nine-year average yields of seed cotton are shown in Table 1. In most cases the yields obtained with dolomitic limestone were slightly higher than those obtained with oyster shell flour. Yield differences between the two sources of lime were not statistically significant except where no fertilizer was applied, and in

TABLE 1.—Effects of Lime and Fertilizer Mixtures on 9-Year Average Yields of Seed Cotton on Loring Silt Loam, Baton Rouge

Fertilizer mixtures, N-P_2O_5-K_2O	Dolomitic limestone	Oyster shell flour	No lime
Pounds per acre	Yield of seed cotton, pounds per acre		
0-64-64	2,064	1,914	1,706
32-64-64	1,985	1,953	1,693
64-64-64	1,920	1,814	1,194
64-32-64	1,800	1,730	1,300
64-0-64	1,232	1,127	747
64-64-32	1,676	1,662	1,135
64-64-0	1,283	1,174	1,008
0-0-0	1,232	1,035	994

Least significant difference at 5 percent level for comparing fertilizer mixtures for any one source of lime = 159 lbs/A.

Least significant difference at 5 percent level for comparing sources of lime for any one fertilizer mixture = 170 lbs/A.

this case the higher yield was obtained with dolomitic limestone. Yield differences between dolomitic limestone and no lime were statistically significant at all levels of fertilization. Yield differences between oyster shell flour and no lime were statistically significant at all levels of fertilization except where potassium was not included in the fertilizer mixture and where no fertilizer was applied.

There were no significant increases in the yield of seed cotton from the application of nitrogen with either source of lime or without lime. The decrease in yield from the application of 64 pounds per acre of nitrogen to the unlimed soil was statistically significant. In most years, especially those with unusually high rainfall during the growing season, plants in the high-nitrogen plots were extremely rank, and yields were reduced to some extent by boll rot. Symptoms of severe manganese toxicity, or crinkle leaf, were also observed in unlimed plots where the 64-pound-per-acre rate of nitrogen had been applied. The very good crops of hairy vetch (Table 4) turned under prior to planting probably account for the lack of significant increases in yield from nitrogen applications.

There were no significant increases in the yield of seed cotton from the application of more than 32 pounds per acre of P_20_5 with either source of lime or without lime. The 32-pound-per-acre increment of P_20_5 increased the yield of seed cotton by 568 pounds per acre with dolomitic limestone, 603 pounds per acre with oyster shell flour and 553 pounds per acre on the unlimed soil. Slight increases in yield were obtained from an additional 32 pounds per acre of P_20_5 with dolomitic limestone and oyster shell flour, but the increases were not statistically significant.

Yield increases from the application of 32 pounds per acre of K_20 were 393 and 488 pounds of seed cotton per acre with dolomitic limestone and oyster shell flour, respectively, as compared with an increase of only 127 pounds of seed cotton per acre on the unlimed soil. An additional 32 pounds per acre of K_20 increased the yields of seed cotton 244 pounds per acre with dolomitic limestone, 152 pounds per acre with oyster shell flour, and only 59 pounds per acre on the unlimed soil. These data suggest that liming accentuates the need for higher rates of K_20 on soils as low as 42 ppm in extractable K.

Potash deficiency symptoms were observed on cotton in the limed plots where K_20 was not included in the fertilizer mixtures. These observations probably illustrate the phenomena explained by Russell (*28*) as ionic antagonism. In this case the relative concentration of calcium and magnesium was increased as a result of liming, which may have reduced the uptake of potassium by the plants. Potassium deficiency symptoms were not observed in plots where potassium was included in the fertilizer mixtures nor in the unlimed plots where potassium was not included in the fertilizer mixture.

The effects of sources of lime and various fertilizer mixtures on earliness of cotton are shown in Table 2. The percentages of the total yield of seed cotton harvested at the first harvest were higher from the limed than from the unlimed plots. The differences in the percentages in favor of lime were more pronounced where the 64-64-64, 64-64-32, and 64-64-0 fertilizer mixtures were used. The cotton plants tended to develop more vegetatively and for a longer period of time on the unlimed plots than on the limed plots where the 64-64-64 mixture was used. This growth characteristic of the plants not only resulted in later maturity, but also in a reduction in yield. Lime apparently reduced the relative vegetative growth of the plants and stimulated earlier maturity.

Potassium deficiency symptoms, such as premature shedding of leaves and improper development and opening of bolls, were more pronounced in limed plots than in unlimed plots where the 64-64-0 mixture was used. In this case, the growth characteristics of the plants due to potassium deficiency resulted in a higher percentage of cotton harvested at the first harvest from the limed plots than from the unlimed plots where potassium was not included in the fertilizer mixtures. The lowest percentage of the total yield of seed cotton harvested at the first harvest

TABLE 2.—Effects of Lime and Fertilizer Mixtures on the Earliness of Cotton on Loring Silt Loam, 6-Year Averages, Baton Rouge

Fertilizer mixtures, N-P_2O_5-K_2O	Dolomitic limestone	Oyster shell flour	No lime
Pounds per acre	Percent total yield harvested at first harvest		
0-64-64	78.9	83.2	78.7
32-64-64	76.9	74.7	70.3
64-64-64	72.9	70.3	59.3
64-32-64	69.5	71.4	62.5
64-0-64	66.6	58.5	56.2
64-64-32	73.9	78.9	57.1
64-64-0	82.2	85.7	67.9
0-0-0	88.9	89.1	85.1

TABLE 3.—Effects of Lime and Fertilizer Mixtures on 4-Year Average Yields of Corn on Loring Silt Loam, Baton Rouge

Fertilizer mixtures, $N-P_2O_5-K_2O$	Dolomitic limestone	Oyster shell flour	No lime
Pounds per acre	- - - - - - - - - - - - - Yield of corn, bushels per acre	- - - - - - - - - - - - -	
0-64-64	53.3	50.7	45.3
64-64-64	64.7	63.9	55.3
96-64-64	70.8	71.0	63.2
96-32-64	67.0	63.7	56.5
96-0-64	47.9	43.9	34.7
96-64-32	66.8	66.8	57.7
96-64-0	63.3	59.7	53.4
0-0-0	36.8	35.1	29.6

Least significant difference at 5 percent level for comparing fertilizer mixtures for any one source of lime = 3.5 bu./A.

Least significant difference at 5 percent level for comparing sources of lime for any one fertilizer mixture = 3.8 bu./A.

was obtained where phosphorus was not included in the fertilizer mixtures applied with or without lime.

The effects of the sources of lime and no lime in combination with the various fertilizer mixtures on the yield of corn are shown in Table 3. Unfavorable weather conditions in 1957 and 1962 were largely responsible for very poor yields of corn for two years of the four-year corn-testing period.

Yields of corn obtained with dolomitic limestone were, in most cases, slightly higher than those obtained with oyster shell flour. The only statistically significant difference in the yield of corn between the two sources of lime occurred when phosphorus was not included in the fertilizer mixtures. In this case, as with cotton, the higher yield of corn was obtained with dolomitic limestone. This difference in yield, 4.0 bushels of corn per acre, suggests that dolomitic limestone increased the effectiveness of soil phosphates more than did oyster shell flour.

Significant increases in the yield of corn were obtained from the use of nitrogen with either source of lime or without lime. The significant increases in yield from the use of nitrogen up to the highest level tested in the experiment, 96 pounds per acre, suggest that a further increase in yield of corn could have been obtained from a rate of nitrogen higher than 96 pounds per acre.

Significant increases in corn yields were also obtained from the application of 32-pound-per-acre increments of P_20_5 up to the highest level of P_20_5 tested in the experiment, 64 pounds per acre, both with and without lime. As shown in Table 3, a 32-pound-per-acre increment of P_20_5 increased the yield of corn 19.1, 19.8, and 21.8 bushels per acre with dolomitic limestone, oyster shell flour, and no lime, respectively. An additional 32 pounds per acre of P_20_5 further increased yields of corn by 3.8 bushels per acre with dolomitic limestone, 7.3 bushels per acre with oyster shell flour, and 6.7 bushels per acre on unlimed soil.

TABLE 4.—Effects of Residual Fertilizers Applied to Cotton and Corn With and Without Lime on the Yield of Hairy Vetch, Baton Rouge

Fertilizer mixtures, $N-P_2O_5-K_2O$*	Dolomitic limestone	Oyster shell flour	No lime
Pounds per acre	Dry weight of vetch, pounds per acre, 3-year average		
0-64-64	4,118	4,507	4,001
32-64-64	4,248	4,234	3,743
64-64-64	3,852	4,332	3,742
64-32-64	4,239	3,788	3,504
64-0-64	3,058	3,124	3,072
64-64-32	4,305	3,858	4,022
64-64-0	3,974	3,746	3,679
0-0-0	2,979	2,788	2,819

*An additional 32 pounds per acre of N was applied to corn as a sidedressing with all fertilizer mixtures except 0-64-64 and 0-0-0.

Least significant difference at 5 percent level for comparing fertilizer mixtures for any one source of lime = 560 lbs/A.

Least significant difference at 5 percent level for comparing sources of lime for any one fertilizer mixture = 688 lbs/A.

Significant increases in the yield of corn were also obtained with the application of 32-pound-per-acre increments of K_20, both with and without lime, up to the highest level of K_20 tested in the experiment—64 pounds per acre. Significant increases in corn yields from applications of 32-pound-per-acre increments each of P_20_5 or K_20 with or without lime suggest also that additional increases in yields could have been obtained from levels of P_20_5 or K_20 higher than the 64-pound level tested in the experiment.

The effects of sources of lime and no lime and the residual effects of the fertilizer mixtures applied to the cotton and corn on the yield of hairy vetch are shown in Table 4. In most cases, the higher yields of vetch were obtained from the limed plots and from those that had received 32 or 64 pounds per acre of P_20_5 in the fertilizer mixtures applied to the cotton and corn. Those plots produced from 600 to 1,000 pounds per acre more vetch, on a dry weight basis, than did those where phosphorus was omitted from the fertilizer mixtures. There was very little difference in the yield of vetch from plots that had received no phosphorus in the fertilizer mixtures and those that had received no fertilizer at all.

Summary

An experiment to study the effects of two sources of lime and no lime in combination with fertilizer mixtures on the yield of cotton, corn, and hairy vetch was conducted over a 13-year period on Loring silt loam at Baton Rouge. The effects of lime and the various fertilizer treatments on earliness of cotton and the residual effects of the treatments on the yield of hairy vetch were also determined.

The average yields of cotton and corn obtained with dolomitic limestone were, in most cases, slightly higher than those obtained with oyster shell flour. Differences in effects on yields between the two sources of lime in favor of dolomitic limestone were statistically significant where no fertilizer was applied to cotton or corn and where phosphorus was omitted from the fertilizer mixture for corn.

Differences in effects on yields between dolomitic limestone and no lime were statistically significant at all levels of fertilization with both cotton and corn. Yield effect differences between oyster shell flour and no lime were statistically significant at all levels of fertilization with corn and at all levels of fertilization with cotton except where potassium was omitted from the fertilizer mixture and where no fertilizer was applied.

In most cases, lower yields of seed cotton were obtained from the application of nitrogen with either source of lime, or with no lime. The decrease in yield of seed cotton with the application of 64 pounds per acre of nitrogen to unlimed soil was statistically significant. Corn yields were significantly increased with applications of up to 96 pounds per acre of nitrogen with both sources of lime and with no lime.

There were no significant increases in yield of seed cotton from the application of more than 32 pounds per acre of P_20_5 with either source of lime or without lime. The significant increases in the yield of corn from the application of 32-pound-per-acre increments of P_20_5 with or without lime suggest that, under the conditions of this experiment, additional increases in corn yields could be expected from applications of phosphorus at rates higher than 64 pounds per acre.

Cotton yields were increased significantly with 32-pound-per-acre increments of K_20 applied with dolomitic limestone and oyster shell flour up to the highest level of K_20 tested in the experiment, 64 pounds per acre.

There was no significant increase in the yield of cotton from a 32-pound-per-acre rate of K_20 applied to unlimed soil. The 64-pound-per-acre rate of K_20 applied to unlimed soil significantly increased the yield of cotton.

The results of this experiment suggest that additional increases in the yield of cotton could be expected from a rate of K_20 higher than 64 pounds per acre applied with either dolomitic limestone or oyster shell flour, and that no further increase in cotton yields could be expected from a rate of K_20 higher than 64 pounds per acre applied to unlimed soil.

Additional increases in the yield of corn could also be expected from a rate of K_20 higher than 64 pounds per acre applied with either source of lime or without lime.

Lime apparently accentuates the need for higher rates of potassium fertilization more with cotton than with corn.

Potash deficiency symptoms were more pronounced in limed plots than in unlimed plots where potassium was not included in the fertilizer mixtures.

A higher percentage of the total yield of cotton was harvested at the first harvest from the limed plots than from the unlimed plots with all fertilizer mixtures.

The lowest percentage of the total yield of cotton harvested at the first harvest was obtained with the 64-0-64 mixture with or without lime.

The highest percentage of the total yield of cotton harvested at the first harvest was obtained where no fertilizer was applied to the limed and unlimed plots.

Where fertilizers were applied, the highest percentage of the total yield of cotton harvested at the first harvest was obtained with the 64-64-0 mixture on the limed plots and the 0-64-64 mixture on the unlimed plots.

The residual effect of fertilizer mixtures applied to cotton and corn on the yield of vetch was more closely associated with phosphorus applications than with nitrogen or potassium applications. Higher yields of vetch were, in most cases, obtained on the limed soil.

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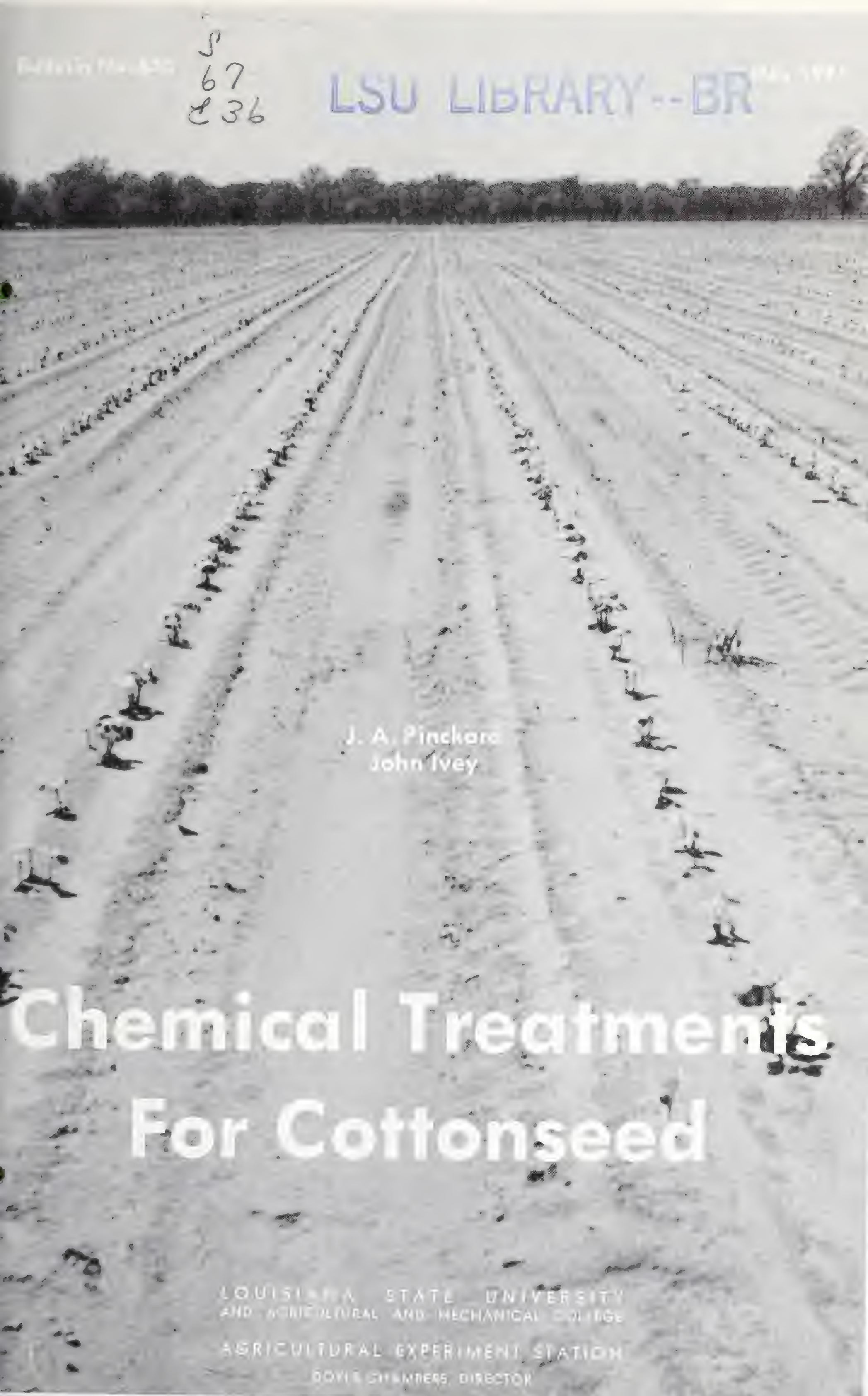

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Chemical Treatments For Cottonseed

LOUISIANA STATE UNIVERSITY
AND AGRICULTURAL AND MECHANICAL COLLEGE

AGRICULTURAL EXPERIMENT STATION
DOYLE CHAMBERS, DIRECTOR

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Foreword

The coating of cottonseed with chemical seed protectants has become a worldwide practice. Almost all recent cottonseed dressings have been based on mercury. In the United States the public has become concerned about mercury as an environmental pollutant. Anticipating the removal of the mercury-based cottonseed dressings from public sale, cotton pathologists, nationwide, undertook to explore non-mercurical substitutes. The agricultural chemical industry has also recognized the need of substitutes for mercury-based pesticides and has synthesized and submitted for testing many excellent chemical formulations.

The testing of chemical dressings for cottonseed is a nationally co-ordinated and cooperative undertaking by the Cotton Disease Council, whose membership consists of interested persons associated with federal, state and industrial laboratories.

The work presented herein covers the 1968, 1969 and 1970 contribution from the Louisiana Agricultural Experiment Station in cooperation with the Cotton Disease Council.

Summary

A three-year field study of 50 chemical coatings on cottonseed for the purpose of discouraging seed rot while improving stands is reported. Substitutes for the alkyl mercury-type seed dressings likely to be removed from the market were sought. Those materials that have met the standards of the Cotton Disease Council and are officially registered with the U.S. Department of Agriculture Pesticides Registration Division are: Arasan, Busan 72, Captan, Dexon, Dithane Z-78, Gallatox, Manzate, Panogen 15, Spergon, Terraclor, Terracoat L-21, Terraclor with Terrazole, and Demosan, the latter to be used only in combination with other fungicidal materials. The conclusions are based on an improved simplified field planting procedure designed to eliminate variation in planting depth, seeding rates and distance between seedlings. The method permits a measure of chemical toxicity as well as preemergence and postemergence disease damage. The method also provides a photographic record of seedling response to chemical treatment of the seed and sufficient material for residue studies, if required.

Chemical Treatments for Cottonseed

J. A. Pinckard[1] and John Ivey[2]

Introduction

Cottonseed normally bears a heavy load of microorganisms in the fuzz. In addition several kinds of bacteria and fungi find their way into the interior of the seed. The soil in which the seed is planted is also well populated with many kinds of microorganisms, some of which are oftentimes destructive to the seed and some are quite beneficial.

For many years it has been known that by coating the seed with certain chemical formulations it is possible to reduce the associated microbial flora to the extent that properly treated seed will produce better stands of seedlings than will untreated seed.

Unfortunately, the disinfectants which have been used for this purpose were, for the most part, volatile mercury compounds having properties poisonous to man and animals as well as microorganisms in general; therefore, mercury-treated seed and seed treated with other economic poisons must not be fed or used for oil but must be destroyed.

In 1936, plant pathologists of the cotton producing states established a non-profit cooperative organization, the Cotton Disease Council, to deal with cotton disease problems on a national basis. As a result a search for substitutes for the mercury seed dressings has been underway for many years by the Council's Committee on Seed Treatments. The results of these studies may be found in the Proceedings of the Cotton Disease Council (*1*)[3] on file in university libraries of the cotton producing states. A study of this mass of data reveals several matters of significance: (a) The alkyl mercury compounds have usually, but not always, been outstanding in their effectiveness. (b) The methods commonly used in testing contain many variables such that the results obtained are often in doubt. (c) Over a period of years the better materials have tended to drift toward more consistently improved stands, but the time and effort required to gain this information by presently used methods is formidable if not prohibitive.

For approval by the Committee on Seed Treatments, a seed disinfectant must have been significantly better than the untreated check in three years of tests. Because these tests are conducted on a cooperative state-by-state basis and because of the extreme variability in results a material meeting the above specifications in one state may not do so in another. For this reason several materials have been approved but only on a state basis (*1*). There is obviously little incentive for a pesticide manufacturer to market a material on such limited sales potential. To be marketed on a national basis a manufacturer's product, as of this writing, must be registered with the USDA, Pesticides Registration Division. To date there are 14 materials registered (Table 15) after roughly 30 years of field tests.

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[2] Formerly Research Assistant; now with Chemagro Chemical Corporation.

[3] Italic numbers in parentheses refer to Literature Cited, page 34.

Anticipating the loss of all mercury seed dressings, the senior writer in 1967 undertook to explore improved methods of testing cottonseed dressings (*35*).

The purpose of this publication, which is part of a larger study, is (a) to describe an improved method of field testing cottonseed dressings and (b) to report on the results of the study, pointing out those materials that are lawfully registered for use on cottonseed in 1970-71 and rating candidate materials now under test which may be approved in future years.

Literature Review

Seedling infection arising from the seed-borne fungus *Glomerella gossypii* (South.) Edg., commonly known as anthracnose, was first demonstrated by Atkinson (*6*) in 1892 and was later confirmed and further emphasized by Barre (*9*) and Edgerton (*19*) in 1912. Experiments by Rolfs (*42*), in 1915, and Faulwetter (*22*), in 1919, showed that *Xanthomonas malvacearum* (E. F. Sm.) Dowson, the pathogen causing bacterial blight of cotton, is also seed-borne. In addition, *Fusarium oxysporum* f. *vasinfectum* (Atk.) Sny. and Han. and *Ascochyta gossypii* Sydow have been reported as seed-borne organisms causing diseases of cotton (*13, 20, 24, 42, 45*). Several other fungi and bacteria have been isolated from the interior of cottonseeds (*16*), including *Rhizoctonia solani* Kühn (*33*) and *Diplodia gossypina* Cke. (*17*). Undoubtedly there are others.

The realization that so many of the more serious diseases of cotton were seed-transmitted led to the development and utilization of germicidal seed treatments. Lyman (*31*), in 1868, reported one of the earliest treatments used in this country in an effort to increase the emergence and survival of cottonseed. It consisted of mixing the seed with moistened wood ashes and common salt. He also stated that some farmers soaked their seed in a solution of salt dissolved in liquid manure, then rolled them in a plaster. These treatments reportedly removed much of the lint and destroyed much of the fungal mycelia and spores carried on the seed coat.

After Atkinson (*7*) found the anthracnose fungus was carried in the seed, he demonstrated that it could be eliminated in some seed lots by treatment with hot water. Other heat treatments for the same purpose were described by Duggar and Cauthen (*18*), Barre (*11*), Lipscomb and Corely (*30*), Lehman (*25*) and Fulton (*23*).

Barre (*10*) found that delinting the cottonseed with sulfuric acid effectively eliminated external infestations of *G. gossypii* and reduced seedling losses resulting from infection by this fungus.

Further studies (*12, 14*) in the use of acids for this purpose led to the development of commercial plants that delint seed under the Brown-Streets (*15*) and Kemgas patents (*36*), which use sulfuric acid and gaseous hydrochloric acid, respectively.

Barre (*8*) and Duggar and Cauthen (*18*) were among the first to attempt to disinfect fuzzy cottonseed with such chemicals as copper sulfate, mercuric chloride and formaldehyde. These treatments were only partially effective, however, and effective treatment with a fungicide became possible after the organic mercurials became available later. Initial studies of these chemicals (*26, 27, 28, 32, 44, 47, 48, 49*) had established by 1930 the effectiveness of ethyl mercury chloride and ethyl mercury phosphate as seed disinfectants for use on cottonseed.

In the decade prior to 1930, the field of "seed protection" began to receive much attention. Until that time, most efforts in seed treatments had been directed towards control of organisms carried either on or within the seed (*4*). Seed protection, as such, is based on the principle of surrounding the seed and/or young seedlings with fungicides which will prevent infection and damage by soil-borne organisms which cause seed rot or damping-off. Previously published observations dating from those of Atkinson (*6, 7*) have ascribed pre- and postemergence damping-off of cotton seedlings to *Rhizoctonia solani* Kühn (*29, 38, 40*), *Glomerella gossypii* (South.) Edg. (*3, 9, 25*), *Fusarium oxysporum* f. *vasinfectum* (Atk.) Sny. and Han. (*43, 46, 50*), other fusaria (*39, 43*), *Sclerotium rolfsii* Sacc. (*21*), *Pythium ultimum* Trow. (*2*), *Phymatotrichum omnivorum* (Shear) Duggar (*41*) and *Thielaviopsis basicola* (Berk.) Ferraris (*37*), to name a few of the more common fungi.

In the years which followed, seed treatment chemicals were sought which would serve as both seed disinfectants and seed protectants, with the primary objective of providing a means of reducing losses from seedling diseases and thereby increasing seedling emergence and survival. Control of these cool-weather diseases was especially pertinent since it had been demonstrated that early planting and a uniform stand of plants were essential in areas infested by the boll weevil (*4, 34*).

In view of the inadequate information on cotton-seedling diseases, the plant pathologists concerned with cotton diseases in 1936 constituted themselves a committee to coordinate studies on the etiology of seedling diseases and to study the possibility of control by seed treatment (*4*).

The Cotton Disease Council was originally organized at the meeting of the Southern Agricultural Workers at Jackson, Miss., in February 1936. The Committee on Cotton Seedling Diseases of the Council immediately planned an extensive series of regional cooperative seed treatment studies. The first was started in the spring of 1936, and these studies have continued on a regional basis since that time (*1*).

The main objective of the cottonseed treatment tests during the years 1936-1939 was to ascertain the relative role of the pathogens infesting cottonseed and the facultative pathogens inhabiting the soil as causes of low seedling emergence and survival (*1, 4*). It was clearly demonstrated that seed treatment with mercurial fungicides reduced seedling losses caused by the seed-borne pathogens, but these treatments did not always eliminate extensive seedling losses when conditions were favorable for seedling infection by soil-inhabiting pathogens (*4, 29, 39*).

Therefore, in 1939, a series of studies was initiated by the Seed Treatment Committee, headed by C. H. Arndt of South Carolina, primarily to study the relative protection that different fungicides in varying dosages might afford cotton seedlings against infection by both soil-inhabiting and seed-borne pathogens (*4, 5*).

In these studies, special combinations of the mercurials and cuprous oxides were included to evaluate the combination of chemicals of proven effectiveness in eliminating the transmission of the anthracnose fungus on and in the seed and in reducing infection of the seedlings by soil-inhabiting fungi.

The seed lots used in these tests were selected through the years from among available planting seed on the basis of their viability and heavy infestation with the anthracnose fungus. Infestation of the seeds by this pathogen was ascertained by germinating untreated seed in flats of steamed sand. Diseased or dead seedlings per 100 seeds planted were counted two weeks after planting to determine the relative incidence of pathogenic organisms carried on the seed (*1, 4*).

The seed lots selected for use were assembled at one location, thoroughly mixed and then divided into portions for the treatments to be applied. The chemicals used for seed treatment were applied usually as dusts in a rotating drum mixer. After treatment, the sublots were divided into requisite amounts and then packaged for shipment to the various cooperators (*1, 4*).

Although the cuprous oxides used in the earlier tests were found to be unsatisfactory as seed protectants on cotton (*4*), these studies started a trend toward the use of various seed-protectant fungicides in combination with the mercurial seed disinfectants which is still in practice.

The evaluation of cottonseed treatment chemicals by the Seed Treatment Committee of the Cotton Disease Council has been based on data obtained from field tests conducted by various cooperators across the cotton belt (*1*). The method of planting, the rate of seeding, the size of the test plot and the final spacing of the plants have been left entirely to the judgement of the individual cooperators. Methods of planting have ranged from hand-dropping seeds to the use of animal-drawn, one-row planters and tractor-drawn, two- and four-row planters. These field tests inevitably had tremendous variation within and among treatments resulting from inconsistencies in the method of planting. Arndt (*4*) reported that regardless of efforts to calibrate mechanical planters equally, he found differences as great as 25 percent in the rate of seeding. In an attempt to develop a more accurate testing procedure, Arndt *(5)* devised a method whereby he placed a known number of seeds, equidistant from one another, on the surface of a long sticky tape, then carried the tape to the field for planting in a narrow trench. He prepared a separate tape for each treatment to be tested and randomized the treatments within the test plot.

With the exception of this one attempt at standardizing the method of planting for use in seed treatment evaluation tests, each of the cooperators has, in years past, planted in his own way and counted seedling emergence and/or final stand as the sole measure of the effectiveness of the seed treatment chemicals. There has been no standardized procedure. In 1967 the senior author undertook to devise more efficient and standard methods of studying cottonseed disinfectants (*35*); a portion of this work is reported herein.

In general, the early practices have been continued to date under the Committee Chairman, Dr. C. D. Ranney, U.S.D.A., formerly of Stoneville, Mississippi, who has provided the treated seed for these studies. One major exception, however, has come about as a result of the gradual disappearance of the anthracnose fungus, probably through continued use of the highly effective mercurial seed disinfectants. The selection of seed lots for use in current studies is no longer based on a high incidence of the seed-borne anthracnose fungus. Seed lots are merely selected on the basis of general fungal infestations, usually determined by incubating untreated seed in rolled-up, moist paper towels (*1*).

Materials and Methods

Source of Seed

Cottonseed of the variety Stoneville 7A were used in the 1968 and 1969 Regional Cottonseed Treatment Tests. Stoneville 213 was used in 1970. The seed were supplied to Dr. C. D. Ranney, USDA and Chairman of the Seed Treatment Committee of the Cotton Disease Council, without charge by the Stoneville Pedigreed Seed Company, Stoneville, Miss., for treatment and distribution to the several states cooperating in the program.

For these cooperative studies Ranney selected seed lots with a germination of 75 to 85 percent to insure not only a high incidence of seed-borne organisms but also a usable stand. The seed lots selected for use showed 81 percent germination in 1968, 78 percent in 1969 and 81 percent in 1970, all with heavy fungal and bacterial populations. In contrast with the early seed treatment studies anthracnose was of minor importance, if present at all.

The seed lots in all three years were equally divided, one-half being acid-delinted and graded on a gravity table to remove some of the small and low-density seed and the other half machine-delinted. By running them through a "Clipper-cleaner" some small and light seed were removed. The seed were then "zip flamed" to remove some of the remaining fuzz. This process probably also removed some of the fuzz-inhabiting microorganisms.

Chemical Seed Treatments Tested

A list showing seed treatments tested, their trade names, chemical definitions and sources of supply is given in Table 1.

Table 1.—Cotton seed treatment chemicals tested in the 1968, 1969 and 1970 cooperative seed treatment evaluation tests in Louisiana and listed according to trade name, chemical definition and source of supply

Trade name	Chemical definition	Source of supply
Arasan 70-S[2]	70% tetramethylthiram disulfide + 2% methoxychlor	duPont
Bay 78175	N, N-dipropyl-N, N'-bis (dichloro fluoromethylthio) sulfamide	Chemagro
Benlate	Methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate	duPont
Buckman TCMBS	40% thiocyanomethylbutylsulfone	Buckman
Buckman TCMTBO	54% 2-(thiocyanomethylthio) benzoxazole	Buckman
Buckman TCMTOB	17% 2-(thiocyanomethylsulfinyl) benzothiazole	Buckman
Busan 72[2]	60% 2-(thiocyanomethylthio)-benzothiazole	Buckman
Captan[2]	N-(trichloromethylthio)-4-cyclohexene-1,2-dicarboximide	Chevron Stauffer
Ceresan L[3]	2.8% methylmercury 2,3-dihydroxypropyl mercaptide + 0.62% methylmercury acetate (2.25% Hg)	duPont
Ceresan M[3]	7.7% N-(ethylmercuri) p-toluene sulfonanilide	duPont
Chemagro 4497	50% bis (1,2,2-trichloroethyl) sulfoxide	Chemagro
Chemagro 5506	2-[(1,2,2-trichloroethyl) dithio] propionamide	Chemagro
Clorox	sodium hypochlorite	Clorox
Daconil	Tetrachloroisophthalonitrile	Diamond Shamrock
Demosan 65 W[2]	1,4-dichloro-2,5-dimethoxybenzene	duPont
Dexon[2]	p-(dimethylamino) benzenediazo sodium sulfonate	Chemagro
Difolatan	Cis-N- [(1,1,2,2-tetrachloroethyl) thiofenyl] -4-cyclohexene-1,2-dicarboximide	Chevron
Dithane Z-78[1,2]	Zinc ethylenebisdithiocarbamate	Rohm & Haas
Gallatox[1,2]	Phenyl mercury acetate	Troy
Gallatox WSP	Phenyl mercury acetate water soluble powder	Troy
Green Cross 2160	Identity not available (organic fungicide)	Sherwin-Williams
HOE 2844	Identity not available (organic fungicide)	American Hoechest
HOE 2874	Identity not available (organic fungicide)	American Hoechest
HOE 2988	Identity not available (organic fungicide)	American Hoechest
HOE 2989	Identity not available (organic fungicide)	American Hoechest
HPMTS	80% 2-hydroxypropylmethanethio sulfonate	Buckman
IM & C 50065-50A	75% benzoyl peroxide + 25% dichlone	Inter. Min. & Chem.

(Table 1 continued on page 10)

Table 1.—(Continued)

Trade name	Chemical definition	Source of supply
IM & C 50065-50B	64.5% benzoyl peroxide + 22% 1,4-dichloro 2,5-dimethoxybenzene + 13.5% (N-trichloromethylthio) 4-cyclohexene-1,2-dicarboximide	Inter. Min. & Chem.
Isobac 20	20% monosodium salt of hexachlorophene	Nationwide
Manzate[1] [2]	80% manganese ethylenebisdithiocarbamate	duPont
Merck MMH	2.25% methyl (8-quinolyloxy)mercury	Merck
Merkyl EPA	5% phenyl mercury ammonium acetate, 1% ethyl mercury ammonium acetate	Vikon
Merkyl PMA	7% phenyl mercuric ammonium acetate	Vikon
Mistomatic	3.5% phenyl mercuric ammonium acetate	Gustafson
Morton EP 368	Identity not available (organic fungicide)	Nor-Am
Morton EP 277 (40 L)	Identity not available (organic fungicide)	Nor-Am
Morton EP 411	Identity not available (organic fungicide)	Nor-Am
Morton EP 473	Identity not available (organic fungicide)	Nor-Am
Morton EP 477	Identity not available (organic fungicide)	Nor-Am
Panocoat E[3]	50% PCNB + 0.76% methylmercury dicyandiamide	Nor-Am
Panocoat F[3]	0.24% methylmercury dicyandiamide + 10% PCNB	Nor-Am
Panogen 15[3]	2.2% cyano (methylmercuri) guanidine, liquid	Nor-Am
PCNB[1] [2]	Pentachloronitrobenzene	Olin
Rhizoctol	24% methylarsinic sulfide, 12% 4-benzoquinone N'-benzoylhydrazone oxime	Bayer AG
Spergon[1] [2]	Tetrachlorobenzoquinone	Uniroyal
Terracoat L-21[2]	22.9% PCNB + 11.4% 5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole	Olin
Terracoat L-205[2]	22.9% PCNB + 5.7% 5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole	Olin
Terracoat 6015-W[2]	60% PCNB + 15% 5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole	Olin
Vitavax	5,6-dihydro-2 methyl-1,4-oxathiin-3-carboxanilide	Uniroyal
Vitavax L	Liquid formulation of above	Uniroyal
Vitavax ST	Powdered preparation of above for use as seed treatment	Uniroyal
Vitavax 75-ST	75% active seed treatment formulation	Uniroyal
Vitavax CLM	Vitavax + an organic mercury (identity not available)	Uniroyal

[1] Tested in previous years.

[2] Currently registered for use on cottonseed in one or more forms (8/1/70).

[3] Recently removed from the market.

Seed Treatment Application Procedures

All fungicides used in these tests were applied to small sublots of seed by using a rotating drum treater. Seed were tumbled for a minimum of five minutes to insure uniform distribution of the chemicals. Liquid formulations, with certain exceptions, were diluted with water and sprayed on the tumbling seed with an atomizer. Fungicides were diluted with water so that the total formulation was equivalent (with certain exceptions) to 1 percent of the seed weight. This method of application was used to facilitate accuracy in measuring the fungicides and to insure maximum seed coverage. Ceresan M, Ceresan M + Demosan, Ceresan M + Vitavax ST, Ceresan L + Demosan, Ceresan L + Vitavax ST, Demosan and Vitavax ST treatments were applied as slurries, which required a moisture content of from 1 to 3 percent of the seed weight.

Materials supplied by the manufacturer as dusts were applied as such, with the exception of those materials listed above. Immediately after application of the fungicide, water (1 percent of the seed weight) was atomized onto the tumbling seed so as to reduce the loss of the dust. No special stickers or other agents were added to any of the materials tested (*35*).

All treatments in the 1968 tests and treatment numbers 1-6 and 8-47 in the 1969 tests were applied by the U.S.D.A., Stoneville, Miss., and treated seed then supplied to each cooperating state. Treatment numbers 7 and 48-53 in the 1969 tests conducted in Louisiana were applied by the authors, using the same procedures as described above, but were tested only in this state. In the 1970 tests treatment numbers 13, 44, 58, 45, 62 and 11 were applied by the authors to untreated seed supplied by the USDA, Stoneville, Mississippi.

Previous Methods of Field Evaluation

The usual field procedure for testing chemical seed treatments for cotton was to place the seed in any convenient 1-, 2- or 4-row planter and either drill or hill-drop at the usual rate per acre. It was assumed that the planter would plant approximately the same number of seed at approximately the same depth for all seed lots. After the seedlings had emerged, seedling counts were made at approximately 2 weeks after planting and again 4 or 5 weeks after planting.

It was assumed that, by using four or more replications, statistical treatment of the data would point to the best materials. Unfortunately the results of tests made by the above procedure have been very erratic, as a study of the data recorded in the Proceedings of the Cotton Disease Council (*1*) reveals. And with the probable removal of all mercurial seed dressings from the market, it seemed essential that a more accurate procedure be developed requiring less extensive field testing for significant differences between materials. The following procedure was devised to overcome some of the above objections.

Revised Method of Field Evaluation

Cottonseed treatment field evaluation tests in Louisiana during the 1968, 1969 and 1970 planting seasons were conducted using a planting procedure different from that of previous years. Field preparation for these tests involved the use of a "Sidewinder" row-shaper on land which had been disked several days earlier (Figure 1). The rows formed by the Sidewinder had smooth, flat tops and were approximately 18 inches wide and 5 inches high. This operation was performed just prior to planting so that the freshly turned soil did not dry excessively before the planting operation was completed.

After the land had been prepared for planting, the field plots were laid out, and individual plots in each of the rows were marked with 12-inch painted stakes placed 36 inches apart down the centers of the rows (Figure 2). These stakes were numbered with a weatherproof pencil, and the numbers on the stakes indicated the number of the seed treatment on the seed to be planted in the plots. The field plot design used for these tests was a randomized block design with eight replications. Acid- and machine-delinted seed were planted in separate plots.

The actual planting operation was directed from a portable table set up at the edge of the field and employed the use of specially designed "planting plates," or "templates," which positioned exactly 50 seed in a uniform pattern at a depth of 1¼ inches.

The planting plate (Figure 3) consisted of two sections: one which will be referred to as the "seed plate," and the other as the "peg plate." The seed plate was constructed of two aluminum rectangles 22 inches long and 10 inches wide. These two plates were fitted one on top of the other and were held in place by stationary guide pins anchored at each corner of the ¼-inch-thick bottom plate. The ⅛-inch-thick top plate was slotted around the guide pins so that it could be moved back and forth on the bottom plate. Both of these plates were drilled with 50 ⅜-inch holes for acid-delinted seed (½-inch holes for fuzzy seed) arranged in five rows of ten so that when the top plate was slid in one direction the 50 holes in each plate would coincide (Figure 4). When the top plate was slid in the opposite direction, the holes did not coincide (Figure 5).

The peg plate (also constructed of a ¼-inch-thick aluminum rectangle having the same dimensions as the seed plate) was fitted with 50 5/16-inch-diameter steel pegs (7/16 for fuzzy seed) 1½ inches long, positioned so that when the peg plate was placed down over the seed plate the pegs on the peg plate would coincide with the holes in the seed plate (Figure 6).

The actual steps involved in the planting operation were as follows:

1. The seed plate was filled with 50 seeds on the table located at the edge of the field plot (Figure 7).
2. The seed plate was then carried to the appropriate plot in the row where the seed it contained were to be planted.

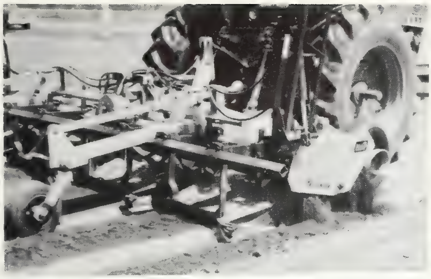

Figure 1.—The "Sidewinder" row-shaper used in preparing the field for planting. The rows formed by the Sidewinder were 5 inches high and 18 inches wide and had smooth, flat tops.

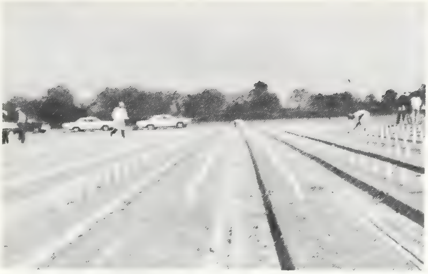

Figure 2.—Individual test plots were demarcated with 12-inch painted stakes placed 36 inches apart down the center of the rows. Numbers on the stakes identified the treatments on the seed to be planted in the plots.

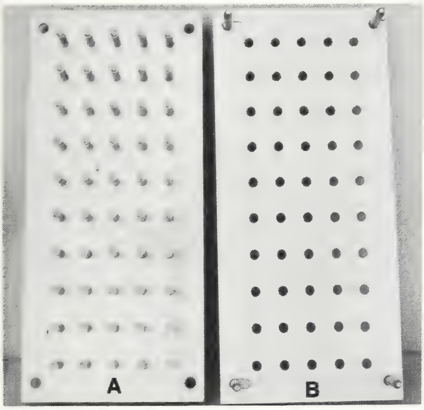

Figure 3.—The "planting plates" used in the planting operation were comprised of two sections: (A) the "peg plate" and (B) the "seed plate."

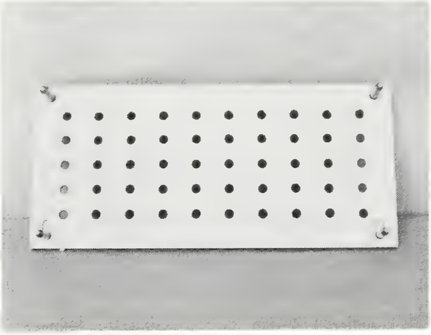

Figure 4.—The seed plate in the open position with the 50 holes in coincidence.

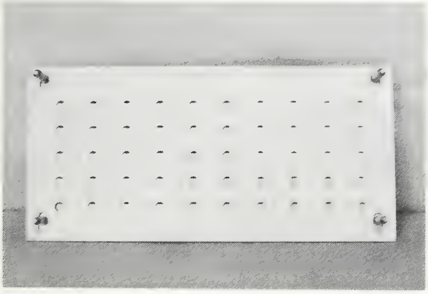

Figure 5.—The seed plate in the closed position.

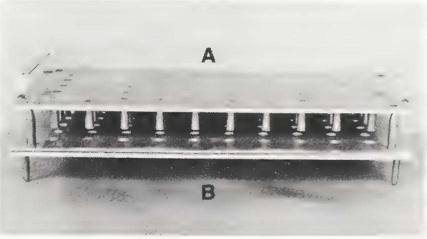

Figure 6.—When the peg plate (A) was placed down over the seed plate (B) the pegs on the peg plate coincided with the holes in the seed plate.

3. The seed plate was then placed on top of the row and pressed firmly to the surface of the soil (Figure 8).
4. The top section of the seed plate was then slid forward allowing the 50 seeds to drop through the holes onto the surface of the soil.
5. The peg plate was then placed down over the seed plate and pressed down firmly until it was flush with the seed plate (Figure 9). This pushed the seed down into the soil to a depth of 1¼ inches.
6. The peg plate was then lifted from the seed plate and placed in the furrow beside the adjacent plot which was next to be planted.
7. The seed plate was then lifted from the surface of the row, and handfuls of soil were spread over the surface of the plot to cover the seed (Figure 10).
8. The seed plate was then carried back to the table to be refilled, and the operation was repeated.

Four men easily planted 50 plots per hour. Seedling emergence counts were made from 11 to 14 days after planting, and 35 mm color slides were made of one representative replication of each treatment for future reference as to whether or not a certain chemical might have produced phytoxicity symptoms on the seedlings. Figure 11 shows a typical individual test plot as it appeared two weeks after planting.

In the 1970 tests an additional stand count was made 33-34 days after planting. At this time all but three of the remaining plants per treatment were removed and weighed and the average weight per seedling recorded (Tables 10 and 13). We believe it essential to leave at least three plants per replication in case additional observations or residue samples are required. The purpose of these observations was to identify those materials having the least stunting effect on the seedlings.

At the Northeast Louisiana Experiment Station the plots were planted on Commerce silt loam, with approximately 80 pounds of nitrogen as ammonia applied several days before planting. Karmex preemergence herbicide was used on all plots.

At the Red River Valley Experiment Station the plots were planted on Norwood silt loam, with approximately 60 pounds of nitrogen as ammonia applied several days before planting, depending upon the weather. Karmex preemergence herbicide was used on all plots.

These fields had been in continuous cotton culture for several years. The dates of planting were, in general, normal for the area. The kinds of pathogenic microorganisms present in the area were not determined precisely, but *Rhizoctonia solani* was found to be the major damping-off organism present, based on laboratory studies of diseased seedlings.

The data obtained from all observations made were statistically analyzed, and the means were compared using Duncan's multiple range test.

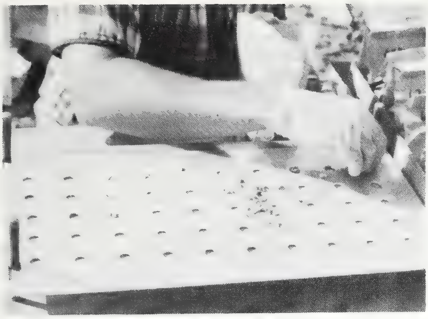

Figure 7.—Step 1 in the planting operation. The seed plate was filled with 50 seed on the table located at the edge of the field.

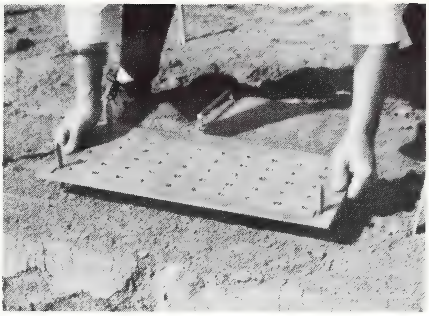

Figure 8.—Step 3 in the planting operation. The seed plate was placed on top of the row and pressed firmly to the surface of the soil.

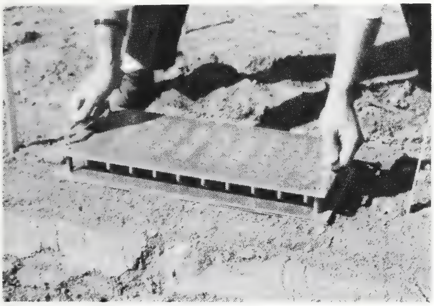

Figure 9.—Step 5 in the planting operation. The peg plate was placed down over the seed plate and pressed down firmly until it was flush with the seed plate. This pushed the seed down into the soil to a depth of 1¼ inches.

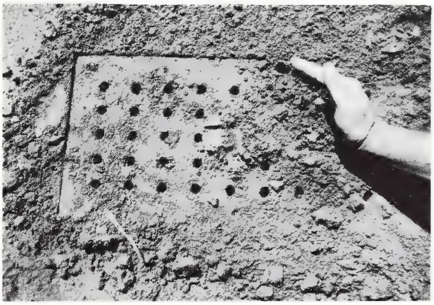

Figure 10.—Step 7 in the planting operation. The seed plate was lifted from the surface of the row, and handfuls of soil were spread over the surface of the plot to cover the seed.

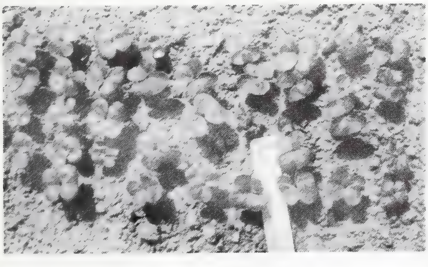

Figure 11.—A typical individual test plot as it appeared two weeks after planting. Seedling emergence counts were made at this time, and 35 mm color slides were made for future reference as to whether or not a certain chemical might have had some effect on the seedlings.

Results

Cottonseed Treatment Field Evaluation Tests—1968

The results of the 1968 cottonseed treatment field evaluation tests conducted at the Northeast Louisiana Agricultural Experiment Station (St. Joseph, La.) on both acid- and machine-delinted seed are shown in Tables 2 and 3, respectively. The treatments in these tests were ranked according to their mean percentage seedling emergence, counted two weeks after planting. Each treatment mean is the average of eight replications. Treatment means were compared using Duncan's multiple range test of significance at the 5 percent level of probability.

Statistical analysis of the results of these tests on acid-delinted seed (Table 2) indicated that all of the treatments tested resulted in seedling stands which were significantly better than that of the untreated check. Of the 30 seed treatment formulations tested, 11 gave results that were not statistically different from the top ranking treatment, Ceresan L + Demosan. Of the 12 highest ranking treatments, seven were non-mercurials. They were: Difolatan, Vitavax L, Morton EP 368, Daconil-Dexon + Demosan, Chemagro 4497, Morton EP 277 (40 L) and Daconil-Captan (40-32).

The results of the seed treatment evaluation tests on machine-delinted seed (Table 3) showed that of the 29 seed treatment formulations tested 17 gave results that were not statistically different from the two top ranking treatments, Daconil-Dexon + Demosan and Ceresan M + Isobac ST. Eight of these top ranking seed treatments were non-mercurials. They were: Daconil-Dexon + Demosan, Vitavax L, Daconil-Captan (40-32), Morton EP 277 (40 L), Vitavax 75-ST, Terracoat L-21, Busan 72 (4.5 oz./100 lbs.) and Daconil-Dexon (40-32).

Cottonseed Treatment Field Evaluation Tests—1969

Red River Valley Agricultural Experiment Station (Bossier City, La.)—The results of the 1969 cottonseed treatment field evaluation tests conducted at the Red River Valley Agricultural Experiment Station on both acid- and machine-delinted seed are shown in Tables 4 and 5, respectively.

As in 1968, statistical analysis of the results of these tests on acid-delinted seed (Table 4) indicated that of the 52 seed treatments tested all except Merkyl PMA gave results that were statistically better than the untreated check. Seventeen of the seed treatments tested gave results that were statistically as good as the top ranking treatment, Difolatan + PCNB. Of the 18 top ranking treatments, eight were non-mercurials. They were: Difolatan + PCNB, Arasan 70-S + Demosan, Daconil-Dexon (40-32) + Demosan, Terracoat L-21, Terracoat L-21 + Vitavax ST, Vitavax ST, Busan 72 + Demosan and Vitavax L.

Statistical analysis of the results obtained from the 47 seed treatments tested on machine-delinted seed at Bossier City (Table 5) showed that 26 were not statistically different from the top ranking treatment, Vitavax 75-ST + Ceresan M. Of the 27 top ranking treatments, 12 were non-mercurials. They were: Vitavax L, IM & C 50065-50A, Busan 72 + Demosan, Arasan 70-S + Demosan, Terracoat L-21, Vitavax 75-ST, Terracoat L-205, Terracoat 6015-W, HOE 2874, Bay 78175, HOE 2844 and Daconil-Dexon (40-32) + Demosan.

Table 2.—Mean seedling emergence of cottonseeds receiving the indicated chemical coatings planted at the Northeast Louisiana Agricultural Experiment Station, St. Joseph, La., April 14, 1968

ACID-DELINTED SEED

Treatment		Dosage (oz./100 lbs.	Mean percent seedling	Indication of
No.	Fungicide	of seed)	emergence[1]	significance[2]
22	Ceresan L + Demosan	2 + 10	84.75	a
18	Vitavax 75-ST + Ceresan M	8 + 2	82.00	ab
21	Ceresan M-Demosan	11	81.25	abc
2	Ceresan M	2	81.00	abcd
32	Difolatan	3	80.50	abcde
19	Vitavax L	8	79.50	abcdef
4	Morton EP 368	6	79.50	abcdef
16	Daconil-Dexon + Demosan	2 + 10	79.00	abcdef
13	Chemagro 4497	2	78.50	abcdef
5	Morton EP 277 (40 L)	3	78.50	abcdef
15	Daconil-Captan (40-32)	2	78.00	abcdefg
24	Ceresan M + Isobac ST	2 + 7	77.75	abcdefg
20	Vitavax L + Ceresan M	8 + 2	77.00	bcdefg
17	Vitavax 75-ST	8	77.00	bcdefg
14	Daconil-Dexon (40-32)	2	76.25	bcdefgh
31	Terracoat L-21	12	76.25	bcdefgh
29	HOE 2844	8	76.00	bcdefghi
12	Busan 72	3	76.00	bcdefghi
3	Morton EP 368	4	74.50	bcdefghij
6	Morton EP 277 + Panogen 15	3 + 2	74.50	bcdefghij
30	HOE 2874	8	73.50	cdefghij
11	Busan 72	2	73.50	cdefghij
7	Panogen 15	2	73.50	cdefghij
28	Merkyl EPA + PCNB	2 + 3	73.25	defghij
23	Ceresan L	2	73.00	efghij
8	Panocoat E	6	71.75	fghij
10	Busan 72	1	70.25	ghij
26	Merkyl PMA + PCNB	2 + 3	68.75	hij
27	Merkyl EPA	2	68.50	ij
25	Merkyl PMA	2	68.25	j
1	Check	0	61.25	k

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 3.—Mean seedling emergence of cottonseeds receiving the indicated chemical coating planted at the Northeast Louisiana Agricultural Experiment Station, St. Joseph, La., April 14, 1968

MACHINE-DELINTED SEED

Treatment		Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
No.	Fungicide			
16	Daconil-Dexon + Demosan	3 + 10	81.75	a
24	Ceresan M + Isobac ST	3 + 9	81.75	a
18	Vitavax 75-ST + Ceresan M	8 +3	80.75	ab
6	Morton EP 277 + Panogen 15	3 + 3	80.50	abc
23	Ceresan L	3	80.00	abc
21	Ceresan M-Demosan	11	79.75	abcd
19	Vitavax L	8	79.50	abcd
15	Daconil-Captan (40-32)	3	79.50	abcd
22	Ceresan L + Demosan	3 + 10	79.50	abcd
5	Morton EP 277 (40 L)	3	79.50	abcd
2	Ceresan M	3	79.25	abcde
9	Panocoat F	30	79.25	abcde
28	Merkyl EPA + PCNB	3 + 3	79.00	abcdef
17	Vitavax 75-ST	8	79.00	abcdef
7	Panogen 15	3	78.50	abcdef
20	Vitavax L + Ceresan M	8 + 3	78.25	abcdef
31	Terracoat L-21	16	78.25	abcdef
12	Busan 72	4.5	75.00	abcdefg
14	Daconil-Dexon (40-32)	3	74.75	abcdefg
25	Merkyl PMA	3	73.25	bcdefg
3	Morton EP 268	4	73.00	bcdefg
4	Morton EP 365	6	72.75	bcdefg
32	Difolatan	4	72.50	bcdefg
27	Merkyl EPA	3	72.25	cdefg
26	Merkyl PMA + PCNB	3 + 3	72.25	cdefg
30	HOE 2874	10	72.25	cdefg
11	Busan 72	3	71.50	defg
10	Busan 72	2	71.00	efg
29	HOE 2844	10	70.75	fg
1	Check	0	69.25	g

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 4.—Mean seedling emergence of cottonseeds receiving the indicated chemical coatings planted at the Red River Valley Agricultural Experiment Station, Bossier City, La., April 23, 1969

ACID-DELINTED SEED

Treatment		Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
No.	Fungicide			
45	Difolatan + PCNB	3 + 4	66.75	a
48	Arasan 70-S + Demosan	3 + 10	65.75	ab
25	Vitavax 75-ST + Ceresan M	8 + 2	65.50	ab
27	Vitavax L + Ceresan M	16 + 2	64.00	abc
40	Ceresan L + Vitavax ST	2 + 8	64.00	abc
16	Merkyl PMA + Vitavax	2 + 10	63.25	abcd
37	Daconil-Dexon (40-32) + Demosan	2 + 10	62.00	abcde
47	Terracoat L-21	12	61.25	abcdef
44	Terracoat L-21 + Vitavax ST	12 + 8	61.00	abcdef
42	Panogen 15 + PCNB + Dexon	2 + 4 + 2	60.75	abcdef
33	Mistomatic + Vitavax L	2 + 16	60.50	abcdefg
46	Rhizoctol + Demosan	3 + 10	60.50	abcdefg
28	Vitavax CLM	16	60.25	abcdefg
32	Merck MMH + Vitavax L	2 + 16	60.00	abcdefg
24	Vitavax ST	8	59.00	abcdefg
31	Panogen 15 + Demosan	2 + 10	59.00	abcdefg
10	Busan 72 + Demosan	2 + 10	58.75	abcdefgh
26	Vitavax L	16	57.00	abcdefghi
20	IM & C 50065-50B	16	55.50	bcdefghij
41	Panogen 15 + Vitavax ST	2 + 8	55.25	bcdefghij
21	Terracoat L-205	12	54.50	cdefghijk
19	IM & C 50065-50A	16	54.25	defghijkl
18	Mistomatic + Demosan	3 + 10	53.00	defghijklm
30	Ceresan L + Demosan	2 + 10	52.25	efghijklmn
36	Daconil-Dexon (40-32)	2	52.00	efghijklmn
38	Ceresan L + PCNB	2 + 4	52.00	efghijklmn
39	Panogen 15 + PCNB	2 + 4	51.50	efghijklmn
23	Isobac 20 + Ceresan M	4 + 2	51.25	efghijklmn
2	Ceresan M	2	51.00	fghijklmn
43	Terracoat L-21 + Dexon	12 + 2	50.75	fghijklmn
34	HOE 2844	8	49.75	ghijklmn
22	Terracoat 6015-W	5	48.50	hijklmno
7	Bay-78175	1	48.00	hijklmno
12	Buckman TCMBS	4	48.00	hijklmno
17	Merck MMH + Demosan	3 + 10	48.00	hijklmno
4	Morton EP 411	2.5	47.00	ijklmnop
11	Buckman TCMTOB	4	47.00	ijklmnop
15	Merkyl PMA + Demosan	2 + 10	46.00	jklmnopq
9	Busan 72	3	45.25	jklmnopq
35	HOE 2874	8	45.00	jklmnopq
52	Green Cross 2160	4	43.75	klmnopq
8	Chemagro 5506	1	43.50	lmnopq
29	Ceresan L	2	43.25	mnopq
14	Merkyl PMA + PCNB	2 + 4	42.75	mnopq
5	Morton EP 411	5	42.00	nopq
3	Morton EP 473	7	41.25	nopq
49	HOE 2988	1.2	38.75	opqr
50	HOE 2989	1.2	36.75	pqr
6	Panogen 15	2	34.75	qr
53	Clorox	5% soak, 10 min.	33.00	qr
51	Isobac 20	4	31.50	rs
13	Merkyl PMA	2	23.25	st
1	Check	0	18.25	t

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 5.—Mean seedling emergence of cottonseeds receiving the indicated chemical coatings planted at the Red River Valley Agricultural Experiment Station, Bossier City, La., April 23, 1969

MACHINE-DELINTED SEED

Treatment		Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
No.	Fungicide			
25	Vitavax 75-ST + Ceresan M	8 + 3	77.00	a
28	Vitavax CLM	16	75.75	ab
26	Vitavax L	16	75.50	abc
38	Ceresan L + PCNB	3 + 4	74.25	abcd
20	IM & C 50065-50A	16	74.25	abcd
41	Panogen 15 + Vitavax ST	3 + 8	74.00	abcd
30	Ceresan L + Demosan	3 + 10	73.75	abcde
27	Vitavax L + Ceresan M	16 + 3	73.75	abcde
10	Busan 72 + Demosan	3 + 10	73.50	abcde
48	Arasan 70-S + Demosan	3 + 10	73.50	abcde
31	Panogen 15 + Demosan	3 + 10	72.50	abcde
15	Merkyl PMA + Demosan	3 + 10	72.50	abcde
47	Terracoat L-21	16	71.25	abcdef
40	Ceresan L + Vitavax 75 ST	3 + 8	71.00	abcdef
24	Vitavax 75-ST	8	70.75	abcdef
16	Merkyl PMA + Vitavax	3 + 8	70.50	abcdef
21	Terracoat L-205	12	70.25	abcdef
39	Panogen 15 + PCNB	3 + 4	69.50	abcdef
2	Ceresan M	3	68.75	abcdef
18	Mistomatic + Demosan	3 + 10	68.75	abcdef
22	Terracoat 6015-W	5	68.25	abcdef
35	HOE 2874	10	68.25	abcdef
6	Panogen 15	3	68.00	abcdef
7	Bay 78175	1	67.50	abcdef
32	Merck MMH + Vitavax L	3 + 16	67.25	abcdef
34	HOE 2844	10	67.00	abcdef
37	Daconil-Dexon (40-32) + Demosan	3 + 10	66.75	abcdef
23	Isobac 20 + Ceresan M	6 + 3	66.25	bcdefg
52	Green Cross 2160	4	65.75	bcdefg
17	Merck MMH + Demosan	3 + 10	65.00	cdefg
36	Daconil-Dexon (40-32)	3	64.25	defghi
33	Mistomatic + Vitavax L	3 + 16	64.25	defghi
5	Morton EP 411	5	64.25	defghi
29	Ceresan L	3	63.25	efghi
19	IM & C 50065-50A	16	62.00	fghi
4	Morton EP 411	2.5	62.00	fghi
9	Busan 72	3.5	61.50	fghi
11	Buckman TCMTOB	5	56.75	ghi
14	Merkyl PMA + PCNB	3 + 4	56.00	hij
53	Clorox	5% soak, 10 min.	55.50	ij
8	Chemagro 5506	2	55.00	ijk
12	Buckman TCMBS	6	54.75	ijk
13	Merkyl PMA	3	50.00	jkl
50	HOE 2989	1.7	49.50	jkl
3	Morton EP 473	7	48.75	jkl
49	HOE 2988	1.7	48.25	jkl
1	Check	0	45.75	kl
51	Isobac 20	4	44.75	l

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Northeast Louisiana Agricultural Experiment Station (St. Joseph, La.).—The results of the 1969 cottonseed treatment field evaluation tests conducted at the Northeast Louisiana Agricultural Experiment Station on both acid- and machine-delinted seed are shown in Tables 6 and 7, respectively.

Statistical analysis of the results of these tests on acid-delinted seed (Table 6) indicated that of the 52 seed treatments tested on acid-delinted seed 27 gave results that were not statistically different from the top ranking treatment, Vitavax L + Ceresan M. Thirteen of the 27 top ranking seed treatments were non-mercurials. They were: Terracoat 6015-W, Terracoat L-21 + Vitavax ST, Daconil-Dexon (40-32) + Demosan, IM & C 50065-50A, Vitavax 75-ST, Terracoat L-21 + Dexon, Difolatan + PCNB, Busan 72 + Demosan, IM & C 50065-50B, Terracoat L-205, Green Cross 2160, Arasan 70-S + Demosan and Morton EP 411 (2.5 oz./100 lbs.).

Results of the seed treatment field evaluation tests on machine-delinted seed planted at St. Joseph (Table 7) indicated that 16 of the 48 treatments tested gave results that were statistically as good as the top ranking treatment, Panogen 15 + Demosan. Eight of the 16 top ranking treatments were non-mercurials. They were: IM & C 50065-50B, Morton EP 411 (5 oz./100 lbs.), Vitavax 75-ST, IM & C 50065-50A, Terracoat 6015-W, HOE 2874, Vitavax L and Busan 72.

Cottonseed Treatment Field Evaluation Tests—1970

The results of the 1970 cottonseed treatment field evaluation tests conducted at the Northeast Louisiana Agricultural Experiment Station (St. Joseph, La.) on both acid- and machine-delinted seed are shown in Tables 8 through 13 inclusive. The treatments in these tests were ranked according to their mean percentage seedling emergence, counted 11-12 days after planting and again 33-34 days after planting. In addition, the average weight of the surviving seedlings was recorded. Each treatment mean is the average of eight replications. Treatment means were compared using Duncan's multiple range test of significance at the 5 percent level of probability.

Statistical analysis of the results of these tests on the emergence of acid-delinted seed after 11-12 days (Table 8) indicated that the 23 treatments used were no better or worse than the untreated check. When survival counts were made 33-34 days after planting (Table 9), 20 of the 23 treatments were significantly better than the check but only two were equal to the best treatment, Rohm & Haas 575. This group included two non-mercurials, Arasan 70-S + Demosan and Rohm & Haas 575. If the average seedling weight is taken as the basis of comparison (Table 10), the mercury formulation of Gallatox WSP + Demosan gave the heaviest seedlings. Emergence, however, was only 3.75 percent above the check (Table 9). Of the five materials giving heavier seedlings than the untreated check (Table 10), four were non-mercurials. These were: HPMTS, Terracoat L-21, IM & C 50065-50 AD and HOE 2989. IM & C

TABLE 6.—Mean seedling emergence of cottonseeds receiving the indicated chemical coatings planted at the Northeast Louisiana Agricultural Experiment Station, St. Joseph, La., April 24, 1969

ACID-DELINTED SEED

Treatment		Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
No.	Fungicide			
27	Vitavax L + Ceresan M	16 + 2	74.00	a
25	Vitavax 75-ST + Ceresan M	8 + 2	72.50	ab
42	Panogen 15 + PCNB + Dexon	2 + 4 + 2	70.75	abc
22	Terracoat 6015-W	5	68.50	abcd
44	Terracoat L-21 + Vitavax ST	12 + 8	68.25	abcd
37	Daconil-Dexon (40-32) + Demosan	2 + 10	68.00	abcd
19	IM & C 50065-50A	16	67.76	abcd
24	Vitavax 75-ST	8	67.50	abcd
33	Mistomatic + Vitavax L	2 + 16	67.00	abcde
40	Ceresan L + Vitavax ST	2 + 8	67.00	abcde
30	Ceresan L + Demosan	2 + 10	66.75	abcdef
38	Ceresan L + PCNB	2 + 4	66.75	abcdef
29	Ceresan L	2	66.50	abcdef
32	Merck MMH + Vitavax L	2 + 16	66.50	abcdef
41	Panogen 15 + Vitavax ST	2 + 8	66.25	abcdefg
43	Terracoat L-21 + Dexon	12 + 2	66.00	abcdefg
28	Vitavax CLM	16	65.50	abcdefg
45	Difolatan + PCNB	3 + 4	65.50	abcdefg
46	Rhizoctol + Demosan	3 + 10	65.25	abcdefg
10	Busan 72 + Demosan	2 + 10	65.00	abcdefg
20	IM & C 50065-50B	16	65.00	abcdefg
16	Merkyl PMA + Vitavax	2 + 8	64.50	abcdefgh
21	Terracoat L-205	12	64.50	abcdefgh
52	Green Cross 2160	4	64.50	abcdefgh
31	Panogen 15 + Demosan	2 + 10	63.75	abcdefgh
48	Arasan 70-S + Demosan	3 + 10	63.75	abcdefgh
4	Morton EP 411	2.5	63.00	abcdefghi
34	HOE 2844	8	62.75	abcdefghi
35	HOE 2874	8	62.75	bcdefghi
11	Buckman TCMTOB	4	62.50	bcdefghi
7	Bay 78175	1	62.25	bcdefghi
23	Isobac 20 + Ceresan M	4 + 2	62.25	bcdefghi
12	Buckman TCMBS	4	61.50	bcdefghij
8	Chemagro 5506	2	61.00	cdefghijk
9	Busan 72	3	61.00	cdefghijk
26	Vitavax L	16	61.00	cdefghijk
6	Panogen 15	2	60.50	cdefghijk
36	Daconil-Dexon (40-32)	2	60.50	cdefghijk
18	Mistomatic + Demosan	3 + 10	60.25	cdefghijk
47	Terracoat L-21	12	58.75	defghijkl
2	Ceresan M	2	58.25	defghijklm
5	Morton EP 411	5	57.75	defghijklm
51	Isobac 20	4	56.25	efghijklm
3	Morton EP 473	7	55.75	fghijklmn
39	Panogen 15 + PCNB	2 + 4	55.50	ghijklmn
17	Merck MMH + Demosan	3 + 10	53.50	hijklmn
15	Merkyl PMA + Demosan	2 + 10	52.75	ijklmn
50	HOE 2989	1.2	52.75	ijklmn
53	Clorox	5% soak, 10 min.	51.00	jklmn
1	Check	0	50.75	klmn
14	Merkyl PMA + PCNB	2 + 4	49.00	lmn
49	HOE 2988	1.2	48.00	mn
13	Merkyl PMA	2	45.75	n

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[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

TABLE 7.—Mean seedling emergence of cottonseeds receiving the indicated chemical coatings planted at the Northeast Louisiana Agricultural Experiment Station, St. Joseph, La., April 24, 1969

MACHINE-DELINTED SEED

Treatment		Dosage (oz./100 lbs.	Mean percent seedling	Indication of
No.	Fungicide	of seed)	emergence[1]	significance[2]
31	Panogen 15 + Demosan	3 + 10	77.25	a
30	Ceresan L + Demosan	3 + 10	74.25	ab
23	Isobac 20 + Ceresan M	6 + 3	72.50	abc
20	IM & C 50065-50B	16	72.00	abcd
41	Panogen 15 + Vitavax ST	3 + 8	72.00	abcd
27	Vitavax L + Ceresan M	16 + 3	71.75	abcd
5	Morton EP 411	5	71.00	abcde
24	Vitavax 75-ST	8	70.75	abcdef
40	Ceresan L + Vitavax ST	3 + 8	70.25	abcdefg
28	Vitavax CLM	16	70.00	abcdefgh
19	IM & C 50065-50A	16	69.50	abcdefghi
38	Ceresan L + PCNB	3 + 4	69.25	abcdefghi
22	Terracoat 6015-W	5	68.50	abcdefghi
35	HOE 2874	10	68.50	abcdefghi
25	Vitavax ST + Ceresan M	8 + 3	68.25	abcdefghi
26	Vitavax L	16	68.00	abcdefghij
9	Busan 72	3.5	67.75	abcdefghij
2	Ceresan M	3	67.25	bcdefghij
10	Busan 72 + Demosan	3 + 10	67.00	bcdefghij
15	Merkyl PMA + Demosan	3 + 10	67.00	bcdefghij
17	Merck MMH + Demosan	3 + 10	66.25	bcdefghij
16	Merkyl PMA + Vitavax	3 + 10	66.00	bcdefghij
47	Terracoat L-21	16	65.75	bcdefghij
48	Arasan 70-S + Demosan 65W	3 + 10	65.75	bcdefghij
49	HOE 2988	1.7	65.75	bcdefghij
6	Panogen 15	3	65.50	bcdefghijk
33	Mistomatic + Vitavax L	3 + 16	65.25	bcdefghijk
37	Daconil-Dexon (40-32) + Demosan	3 + 10	65.00	bcdefghijk
52	Green Cross 2160	4	64.50	bcdefghijk
39	Panogen 15 + PCNB	3 + 4	64.25	bcdefghijk
34	HOE 2844	10	64.00	bcdefghijk
21	Terracoat L-205	12	63.50	cdefghijk
3	Morton EP 473	7	63.25	cdefghijk
7	Bay 78175	1	63.25	cdefghijk
29	Ceresan L	3	63.25	cdefghijk
12	Buckman TCMBS	6	62.25	cdefghijk
1	Check	0	62.00	defghijk
36	Daconil-Dexon (40-32)	3	61.75	defghijk
13	Merkyl PMA	3	61.00	efghijk
8	Chemagro 5506	2	60.75	efghijk
11	Buckman TCMTOB	5	60.75	efghijk
50	HOE 2989	1.7	60.75	efghijk
14	Merkyl PMA + PCNB	3 + 4	60.50	fghijk
32	Merck MMH + Vitavax L	3 + 16	60.25	ghijk
4	Morton EP 411	2.5	59.75	hijk
18	Mistomatic + Demosan	3 + 10	50.50	ijk
51	Isobac 20	4	57.75	jk
53	Clorox	5% soak, 10 min.	55.50	k

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

50065-50 AD gave a seedling survival of only 7.25 percent above the check, while Rohm & Haas 575 gave a survival of 14 percent above the check (Table 9). Unfortunately, many of the better materials, from the standpoint of emergence and survival, produced some seedling injury, which is indicated by mean seedling weight (Tables 10 and 13).

The results of emergence of machine-delinted seed after 11-12 days (Table 11) indicated that of the 32 materials tested 31 gave emergence percentages superior to the untreated check. Of this group Benlate and Ceresan L gave an emergence of 71.75 percent, or 16.75 percent better than the check. Three other materials were statistically equivalent. These were: Vitavax L, Vitavax + Thiram and Dexon.

Seedling survival from these same seed lots after 33-34 days (Table 12) gave slightly different results. Of the 32 materials tested all were significantly superior to the untreated check. Two were statistically

Table 8.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and mean seedling emergence 11-12 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

ACID-DELINTED SEED

Treatment No.	Materials used	Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
49	Gallatox WSP + Vitavax	0.7 + 8	74.00	a
35	Terracoat L-205	24	71.50	a
41	Bay 78175	2.5	71.50	a
10	Vitavax + Captan (mix)	8	69.25	a
30	Rohm & Haas 575	6	69.25	a
2	Ceresan M	2	68.00	a
3	Busan 72	3	67.50	a
28	Rohm & Haas 893	4	67.50	a
42	IM & C 50065-50 AD	16	67.50	a
32	HOE 2989	8	66.00	a
51	Gallatox WSP + PCNB 75	0.7 + 4	66.00	a
6	HPMTS	5	65.50	a
8	Vitavax + Thiram (mix)	8	65.50	a
38	Arasan 70-S + Demosan	3 + 10	64.75	a
7	Vitavax L	8	63.75	a
43	IM & C 50065-50 AS	16	63.50	a
48	Gallatox WSP	0.7	63.25	a
4	Busan 72 + Demosan	2 + 10	61.50	a
1	Check	0	61.25	a
29	Rohm & Haas 058	2	60.25	a
33	Terracoat L-21	12	60.25	a
50	Gallatox WSP + Demosan	0.7 + 10	60.25	a
5	TCMTBO	1.5	59.25	a
37	Arasan 70-S	3	58.25	a

[1] Each mean is the average of eight replications.

[2] Not significant.

equivalent to the best formulation, Gallatox WSP + Demosan, a mercurial formulation. One non-mercurial formulation, Daconil + Dexon, was in this class. This material had a survival percentage of 15.5 percent more than the untreated check.

The weight of the seedlings, which is sometimes a partial indication of chemical toxicity of the treatments, showed only two non-mercurial base materials superior to the untreated check (Table 13). These were Maneb and Terracoat L-21.

Table 9.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and mean seedling survival 33-34 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

ACID-DELINTED SEED

Treatment No.	Materials used	Dosage (oz./100 lbs. seed)	Mean percent survival[1]	Indication of significance[2]
30	Rohm & Haas 575	6	74.50	a
49	Gallatox WSP + Vitavax	0.7 + 8	74.50	a
38	Arasan 70-S + Demosan	3 + 10	73.75	ab
28	Rohm & Haas 893	4	72.25	bc
51	Gallatox WSP + PCNB 75	0.7 + 4	72.00	bc
2	Ceresan M	2	71.25	bcd
35	Terracoat L-205	24	70.75	cde
43	IM & C 50065-50 AS	16	70.50	cdef
41	Bay 78175	2.5	70.00	cdef
10	Vitavax + Captan (mix)	8	69.00	def
29	Rohm & Haas 058	2	68.50	defg
3	Busan 72	3	68.25	efg
4	Busan 72 + Demosan	2 + 10	68.25	efg
8	Vitavax + Thiram (mix)	8	68.00	efghi
42	IM & C 50065-50 AD	16	67.75	fghi
7	Vitavax L	8	66.00	ghij
32	HOE 2989	8	65.50	hijk
5	TCMTBO	1.5	65.25	ijk
50	Gallatox WSP + Demosan	0.7 + 10	64.25	jk
37	Arasan 70-S	3	64.00	jk
33	Terracoat L-21	12	63.25	kl
6	HPMTS	5	63.00	klm
48	Gallatox WSP	0.7	61.25	lm
1	Check	0	60.50	m

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 10.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and weight of seedlings 33-34 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

ACID-DELINTED SEED

Treatment No.	Materials used	Dosage (oz./100 lbs. seed)	Mean weight[1]	Indication of significance[2]
50	Gallatox WSP + Demosan	0.7 + 10	4.0926	a
6	HPMTS	5	3.9333	b
33	Terracoat L-21	12	3.7720	c
42	IM & C 50065-50 AD	16	3.7154	cd
32	HOE 2989	8	3.7085	cd
1	Check	0	3.7078	cd
28	Rohm & Haas 893	4	3.7020	cd
41	Bay 78175	2.5	3.6761	cde
3	Busan 72	3	3.6429	cdef
5	TCMTBO	1.5	3.6323	cdefg
10	Vitavax + Captan (mix)	8	3.6229	cdefg
7	Vitavax L	8	3.5955	defg
30	Rohm & Haas 575	6	3.5827	defgh
2	Ceresan M	2	3.5686	defgh
51	Gallatox WSP + PCNB 75	0.7 + 4	3.5337	efgh
49	Gallatox WSP + Vitavax	0.7 + 8	3.5289	efgh
8	Vitavax + Thiram (mix)	8	3.4897	fgh
37	Arasan 70-S	3	3.4832	gh
43	IM & C 50065-50 AS	16	3.4270	h
29	Rohm & Haas 058	2	3.4209	h
38	Arasan 70-S + Demosan	3 + 10	3.2525	i
35	Terracoat L-205	24	3.2281	ij
48	Gallatox WSP	0.7	3.2096	ij
4	Busan 72 + Demosan	2 + 10	3.0906	j

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 11.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and mean seedling emergence 11-12 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

MACHINE-DELINTED SEED

Treatment No.	Materials used	Dosage (oz./100 lbs. of seed)	Mean percent seedling emergence[1]	Indication of significance[2]
13	Benlate	8	71.75	a
52	Ceresan L	3	71.75	a
7	Vitavax L	8	71.00	ab
8	Vitavax + Thiram (mix)	8	70.00	abc
44	Dexon	1.5	69.50	abcd
10	Vitavax + Captan	8	69.25	bcd
58	Maneb	16	69.25	bcd
57	Daconil + Dexon	8 + 7	69.00	bcd
29	Rohm & Haas 058	3	67.75	cde
37	Arasan 70-S	3	67.75	cdef
45	Daconil	1.5	67.50	def
49	Gallatox WSP + Vitavax	1 + 8	67.25	def
2	Ceresan M	3	66.00	efg
35	Terracoat L 205	24	65.75	efgh
28	Rohm & Haas 893	6	65.25	fghi
51	Gallatox WSP + PCNB 75	1 + 4	65.25	fghi
48	Gallatox WSP	1	64.75	ghi
4	Busan 72 + Demosan	3 + 10	64.50	ghi
32	HOE 2989	8	63.75	ghi
33	Terracoat L-21	16	63.50	ghij
62	Vitavax L	16	63.50	ghij
6	HPMTS	6	63.25	hijk
56	Captan 75	3	62.75	ijkl
38	Arasan 70-S + Demosan	3 + 10	62.50	ijkl
43	IM & C 50065-50 AS	16	62.50	ijkl
41	Bay 78175	5	61.50	jklm
50	Gallatox WSP + Demosan	1 + 10	61.00	klmn
5	TCMTBO	2	60.25	lmno
3	Busan 72	3.5	59.50	mno
11	Demosan	10	58.50	no
42	IM & C 50065-50 AD	16	57.75	o
1	Check	0	55.00	p
30	Rohm & Haas 575	7	51.75	q

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 12.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and mean seedling survival 33-34 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

MACHINE-DELINTED SEED

Treatment No.	Materials used	Dosage (oz/100 lbs. seed)	Mean percent emergence[1]	Indication of significance[2]
50	Gallatox WSP + Demosan	1 + 10	75.75	a
52	Ceresan L	3	74.75	ab
57	Daconil + Dexon	8 + 7	74.00	abc
58	Maneb	16	73.00	bcd
44	Dexon	1.5	72.50	cde
56	Captan 75	3	72.25	cdef
49	Gallatox WSP + Vitavax	1 + 8	71.50	defg
7	Vitavax L	8	70.50	efgh
10	Vitavax + Captan (mix)	8	70.25	fghi
38	Arasan 70-S + Demosan	3 + 10	70.25	fghi
37	Arasan 70-S	3	70.00	ghi
2	Ceresan M	3	69.75	ghi
8	Vitavax + Thiram (mix)	8	69.50	ghi
41	Bay 78175	5	68.75	hij
51	Gallatox WSP + PCNB 75	1 + 4	68.75	hij
29	Rohm & Haas 058	3	68.50	hijk
62	Vitavax L	16	68.50	hijk
4	Busan 72 + Demosan	3 + 10	68.25	ijkl
42	IM & C 50065-50 AD	16	68.25	ijkl
48	Gallatox WSP	1	67.25	jkl
28	Rohm & Haas 893	6	67.00	jklmn
45	Daconil	1.5	67.00	jklmn
13	Benlate	8	66.75	jklmn
6	HPMTS	6	66.50	klmno
30	Rohm & Haas 575	7	66.50	lmno
35	Terracoat L-205	24	66.25	lmno
43	IM & C 50065-50 AS	16	65.75	mno
32	HOE 2989	8	65.25	nop
5	TCMTBO	2	64.50	opq
11	Demosan	10	63.50	pq
3	Busan 72	3.5	62.50	q
33	Terracoat L-21	16	62.50	q
1	Check	0	58.50	r

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Table 13.—List of chemical seed treatments tested in Louisiana in cooperation with the Regional Cottonseed Treatment Committee, dosages used and weight of seedlings 33-34 days after planting, April 24-25, 1970, Northeast Louisiana Experiment Station, St. Joseph, La.

MACHINE-DELINTED SEED

Treatment No.	Materials used	Dosage (oz./100 lbs. seed)	Mean weight[1]	Indication of significance[2]
58	Maneb	16	3.5922	a
33	Terracoat L-21	16	3.5225	ab
49	Gallatox WSP + Vitavax	1 + 8	3.4602	bc
13	Benlate	8	3.4512	bc
1	Check	0	3.4339	bc
44	Dexon	1.5	3.4265	bc
37	Arasan 70-S	3	3.3818	bcd
10	Vitavax + Captan (mix)	8	3.3714	cde
45	Daconil	1.5	3.3191	def
52	Ceresan L	3	3.3133	ef
51	Gallatox WSP + PCNB 75	1 + 4	3.2807	efg
28	Rohm & Haas 893	6	3.2747	efgh
6	HPMTS	6	3.2404	fgh
41	Bay 78175	5	3.2337	fgh
8	Vitavax + Thiram (mix)	8	3.2332	fgh
7	Vitavax L	8	3.2236	fgh
57	Daconil + Dexon	8 + 7	3.2094	fghi
43	IM & C 50065-50 AS	16	3.1844	ghij
38	Arasan 70-S + Demosan	3 + 10	3.1798	ghij
35	Terracoat L-205	24	3.1664	hijk
2	Ceresan M	3	3.1099	ijkl
48	Gallatox WSP	1	3.1011	jkl
5	TCMTBO	2	3.0959	jklm
42	IM & C 50065-50 AD	16	3.0893	jklm
62	Vitavax L	16	3.0591	klmn
4	Busan 72 + Demosan	3 + 10	3.0038	lmno
30	Rohm & Haas 575	7	2.9923	mno
11	Demosan	10	2.9868	no
29	Rohm & Haas 058	3	2.9424	o
32	HOE 2989	8	2.9403	o
3	Busan 72	3.5	2.9326	o
50	Gallatox WSP + Demosan	1 + 10	2.9224	o
56	Captan 75	3	2.9079	o

[1] Each mean is the average of eight replications.

[2] Means followed by the same letter(s) are not significantly different at the 5% level of probability.

Discussion

Evaluation of the Planting Method

Variations in seedling stands resulting from inconsistencies in the rate of seeding and depth of planting, which usually occur with the use of conventional planting methods, cause those methods to be of questionable value for use in seed treatment evaluation tests. The variation within and between treatments which results from these inconsistencies in planting is sometimes too great to allow for accurate determinations of differences between treatments. For that reason, field tests conducted in Louisiana for the evaluation of cottonseed treatment chemicals have, for the past three years, been planted using the "planting plate" described in the preceding pages. Field evaluation of seed treatments using this method of planting allow for a more accurate determination of real differences between treatments for the following reasons:

1. The number of seeds planted in each individual replication is exact and constant.
2. All seeds are planted at a uniform 1¼-inch depth.
3. The uniform planting depth results in a more even rate of emergence.
4. The land area required for the evaluation of large numbers of treatments is greatly reduced, thereby probably resulting in a reduction of the effects of soil heterogeneity.
5. There is no chance of a sampling error occurring in making the seedling counts since all emerging seedlings in each replication are counted after 11 to 14 days and all surviving seedlings are counted after 33 to 34 days.
6. Seedling counts are easier to make as a result of the uniform planting pattern.
7. Photographs of a representative replication (Fig. 11) are on record for further study should additional comparisons be desirable.
8. Seedlings are harvested and weighed after 4 to 5 weeks to obtain a measure of seedling vigor. Three plants of each replication may be left in the plot for further use if needed for residue samples or for additional study.

No direct comparison was undertaken in Louisiana between conventional planting methods and the one described herein. However, a comparison is possible by studying the results of the Cooperative Regional Cottonseed Treatment Tests, an example of which is published in the 1969 Seed and Soil Treatment Newsletter (*38*). In these tests, conducted in 10 states at 27 locations wherein seed of the same seed lot was planted, using methods of the cooperators' choice, the "LSD" at the 5 percent level ranged from a low of 3.5 for Louisiana to a high of 22 in another state. Three locations showed no significant differences. At the 1 percent level the differences ranged from 4.9 for Louisiana to 28.3. Six locations reported no significant differences.

The higher the "LSD" number, the more difficult it becomes to be sure that observed differences between treatments are real. At test locations where no significant differences were observed between treated and untreated seed the question remains: Was seed treatment of no real value, or were the circumstances such that differences could not be demonstrated by the method used?

Evaluation of the Seed Dressings

We have used the term "seed dressings" throughout this report for the reason that coatings applied to seeds are of many kinds, not necessarily disinfectants. The physical and chemical nature of the formulation itself also oftentimes affects performance. The term "seed treatment" may refer to dressings applied, heat treatments, types of storage or delinting methods, all of which affect seedling emergence and survival.

No attempt will be made to discuss in detail all of the results presented, although several interesting relationships are noted. For example, the compound Demosan does not seem to be of much value as a seed disinfectant or protectant (Tables 11, 12, treatment no. 11). As with Isobac 20 (Tables 6, 7, treatment no. 51), its performance improved when it was combined with other materials. Isobac 20 is known to be a very powerful bacterial disinfectant although quite selective. Clorox, as a 5 percent soak for 10 minutes (Table 7, treatment no. 53), is known to be a very efficient general disinfectant. Surprisingly, Clorox has proved to be of no value as a seed treatment. Relationships of this type point to the possibility of certain very basic phenomena involving seed germination and emergence in relation to their microecology. Reference to Table 14 shows a group of non-mercurials several of which are not now registered with the U.S.D.A. Pesticides Registration Division but which are statistically equal to or better than the standard, Ceresan M. One of these materials, Vitavax, is a systemic fungicide, i.e., when taken into the plants by way of the roots it blocks the invasion of *Rhizoctonia*-caused seedling blight.

Before a cottonseed disinfectant can be used in commerce it must be registered with the Pesticides Registration Division of the U. S. Department of Agriculture. At the present time (November, 1970) only those materials and dosages listed in Table 15 have been registered for this use. To properly interpret the results of our past research we must choose those materials showing the most consistent and satisfactory results within the framework of the current regulations. Furthermore, the Cotton Disease Council has stipulated that it will approve only those materials which have been in the cooperative test program for three years and which show a statistically significant improvement, at the 5 percent level, over the untreated check seed. Ceresan M, the accepted standard, falls well within these requirements; however, it is an

Table 14.—Summary of materials used,[1] dosage, number of tests completed and average percent emergence of cotton seedlings[2]

Material used	Dosage (oz. per 100 lbs. seed)	Number of tests	Years tested	Average percent emergence
Vitavax 75-ST	8	6	2	70.66
Vitavax L	8	5	3	69.30
Ceresan M	3	6	3	68.91
BUSAN 72 + DEMOSAN	3 + 10	4	2	68.25
TERRACOAT L-21	16	5	3	68.25
PANOGEN 15 + DEMOSAN	3 + 10	4	3	68.13
ARASAN 70-S + DEMOSAN	3 + 10	7	2	67.89
Daconil + Dexon (40-30)	2	5	3	66.35
Vitavax L	16	6	3	65.58
IM & C 50065-50A	16	5	2	65.55
TERRACOAT L-21	12	4	3	64.87
PANOGEN 15	3	6	3	63.46
Terracoat 6015-W	5	4	1	63.43
BUSAN 72	3	4	3	62.62
Morton 411	5	4	1	58.75
Check	0	10	3	53.75

[1] Only those materials are listed which have been used in four or more tests (see preceding tables).

[2] Materials in capital letters and underlined were registered for use with the U.S.D.A. Pesticides Registration Division as of November 15, 1970.

alkyl mercury and for this reason it and related mercury seed dressings have been or are likely to be removed from the market.

Of all the materials tested in the past three years, those which have been significantly superior to the untreated check at the 5 percent level of probability and have been in at least four tests are rated in Table 14, which also shows the dosage used, the number of years tested and the average emergence in all tests.

All the non-registered materials listed which have been in the tests three years and meet the requirements for recommended use are therefore worthy candidates for registration with the Pesticides Registration Division of the U.S.D.A., as substitutes for the alkyl mercury seed dressings. These are: Vitavax L (8 oz.), Daconil-Dexon (40-30) and Vitavax L (16 oz.).

At the present time Terracoat L-21 is properly registered and has been in our tests for three years. Additionally, Terracoat L-21 at 12 oz./100 lbs. on acid-delinted seed (Table 10) and at 16 oz. on machine-delinted seed (Table 13) did not significantly interfere with the weight of the seedlings as did many other materials, including the standard treatment, Ceresan M.

The other materials listed in Table 15 have shown significant stand improvements during the past 10 years in other tests. These improve-

Table 15.—Materials officially registered for cottonseed treatment with the U.S. Department of Agriculture, Pesticides Registration Division, with recommended dosages as of August 1, 1970

			Registered ave. rates (oz. active per 100 lbs. seed)		
Common name	Trade name	Seed type	Dry	Slurry	Liquid
Captan	Captan	All	2.7	4.0	—
Chloranil	Spergon	Acid del.	4.1	2.9	—
Chloranil	Spergon	Mach. del.	2.9	3.8	—
Chloranil	Spergon	Fuzzy	5.7	—	—
Chloroneb[1]	Demosan[1]	All	8.0	6.5	—
Maneb	Manzate	All	9.6	—	—
Thiram	Arasan	Acid del.	3.0	2.33	—
Thiram	Arasan	Mach. del.	—	—	—
Thiram	Arasan	Fuzzy	—	—	—
Zineb	Dithane Z-78	Acid del.	1.05	0.84	—
Zineb	Dithane Z-78	Mach. del.	1.47	1.26	—
Zineb	Dithane Z-78	Fuzzy	2.94	2.10	—
Not assigned	Busan 72	Mach. del.	—	—	3.5
Not assigned	Busan 72	Acid del.	—	—	3.0
Not assigned	Dexon	All	1.5	2.1	—
Not assigned	Gallatox	Acid del.	—	—	2.0-4.0
Not assigned	Gallatox	Mach. del.	—	—	3.0-6.0
Not assigned	Gallatox	Fuzzy	—	—	4.5-9.0
Not assigned	Panogen 15	Fuzzy	—	—	4.5
Not assigned	Panogen 15	Mach. del.	—	—	3.0
Not assigned	Panogen 15	Acid del.	—	—	2.0
Not assigned	Terraclor	All	—	—	4.0
Not assigned	Terracoat L-21	Acid del.	—	—	12.0
Not assigned	Terracoat L-21	Mach. del.	—	—	16.0
Not assigned	Terracoat L-21	Fuzzy	—	—	20.0
Not assigned	Terraclor (with Terrazole 1 oz./cwt.)	Acid del.	—	—	4.0
Not assigned	Terraclor (with Terrazole 1.25 oz./cwt.)	Mach. del.	—	—	5.0
Not assigned	"	Fuzzy	—	—	6.0

[1] Not to be used alone, but with other fungicidal seed dressings.

ments have been erratic, probably because of the crude methods of testing. Inasmuch as these materials are registered for use and have shown stand improvements they should be reinvestigated under more precise methods such as suggested herein.

Further examination of the tables presented indicates that several presently non-registered materials such as Vitavax, Daconil + Dexon, IM & C 50065-50A and Morton 411 are potentially useful materials, based on these methods of testing. It should be emphasized, however, that because a material must be in the cooperative tests for three years before it can be approved, it is wise for its sponsor to select one formulation and dosage and keep it in the tests. To shift dosages and combinations of materials only adds confusion and extends the test to additional years.

It is therefore suggested that the commercial interests test their own variations of dosages, combinations and formulations, using the method described herein or a suitable variation, and submit to the Committee their one or two best efforts for three consecutive seasons.

The results of this study show that the uniform method of planting described is highly accurate and practical for field use. The study also points out the value of seedling *emergence* counts and color photographs of the plots for chemical injury records. A final *survival* count at the age of 4 to 5 weeks, with average seedling weight records, indicates a degree of postemergence damping-off control and/or chemical injury, if present. Some judgment based on frequent observations is necessary for proper interpretation of this kind of data. It seems advisable to leave at least three plants per replication so that later use may be made of them for residue analysis or other purposes.

No attempt has been made to discuss the many implications suggested by the data presented for the materials other than those mentioned. It should be emphasized, however, that in view of the wide use of systemic insecticides in combination with seed dressings it seems almost useless to test one without the other if the best interest of the grower is to be served effectively.

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Returns Above Feed and Steer Costs From Finishing Steers on Experimental Rations in Louisiana

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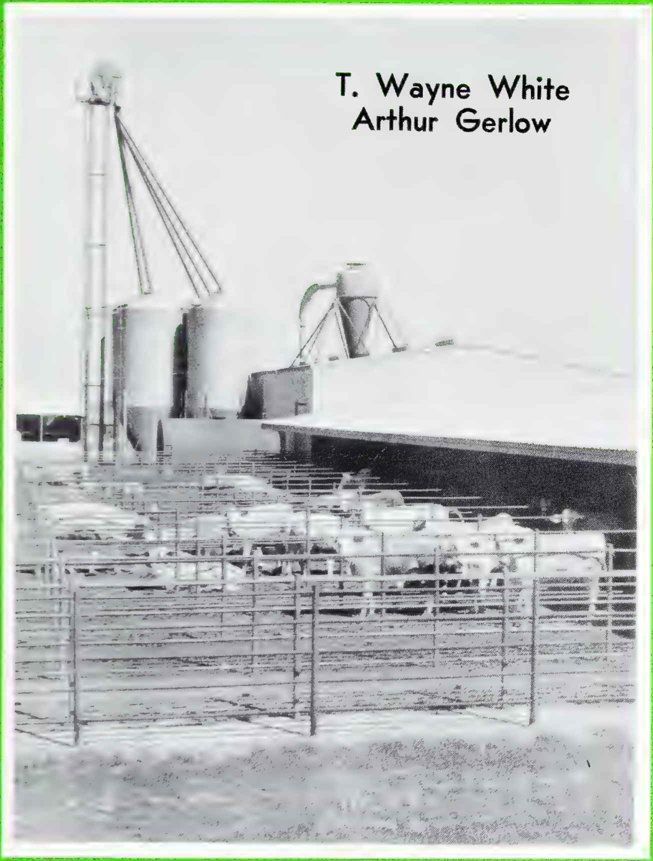

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COVER PICTURE

The picture on the cover shows feedlot facilities used in studies at the Rice Experiment Station, Crowley, Louisiana.

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Abstract

This report describes the results of feeding 64 rations to 740 steers in 14 feedlot trials at the Rice Experiment Station, Crowley, Louisiana. A decription of the rations, the physical inputs and outputs associated with each ration, and the costs and returns resulting from the input-output relationships are shown in tabular form with a brief discussion of each table. Results of the analysis showed a wide range ($.16 to $.25) in gain cost (per pound) between rations. Cost reductions usually resulted from the inclusion of rice bran and molasses in the ration and from substituting urea for all or part of the protein.

Key words: Cattle feeding, experiment, rations, performance, costs, efficiency, Louisiana, budgeting.

Returns Above Feed and Steer Costs from Finishing Steers on Experimental Rations In Louisiana

T. Wayne White and Arthur Gerlow*

Beef production in Louisiana consists primarily of feeder calves. However, a potential exists for feeding cattle since the feeder cattle are available, forage is plentiful for grazing prior to feeding, roughage is abundant, and grain crops are increasing. These factors, in addition to relatively high cattle prices, have stimulated interest in feeding cattle to heavier weights for slaughter.

Some of the questions asked most frequently about feeding cattle are: What rations should be fed? what will the rations cost? what returns can be expected? In this publication, data are presented on the performance of steers fed various alternative rations at the Rice Experiment Station, Crowley, Louisiana. It is an attempt to answer some questions regarding feed cost, cost of gain, and expected returns above feed cost.

Literature Review

Saunders, *et al.* (1966) reported data indicating the feed cost per pound of gain would be about 17 cents when 500-pound steers were fed a ration containing ground shelled corn, cottonseed meal, and Coastal bermuda hay for 180 days. Johnson and Eckert (1968) reported that feed costs per pound of gain ranging from 14.95 to 17.38 cents, depending on the age of the cattle, represented from 68 to 77% of the total cost of gain. Likewise, Blosser (1969) found that feed cost amounted to 17.85 cents per pound of beef produced, or 71% of total cost. Gee (1969) reported a feed cost per pound of gain of 18.86 cents in Colorado feedlots when 586-pound steers were fed for 198 days. Gee (1970) reported total costs per pound of gain of 19.7, 20.7, and 21.7 cents in custom feedlots when steers weighed under 500, 500 to 699, and over 700 pounds, respectively. The respective feed conversions were 7.54, 7.84, and 8.02. Johnson, Vaile, and Youde (1970) reported that feed costs per pound of gain were 22.18, 19.94, 17.35, 16.39, 19.40, 19.63, and 14.35 cents in northwestern feedlots with capacities of 1 to 999, 1,000 to 2,749, 2,750 to 5,999, 6,000 to 11,499,

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11,500 to 19,999, 20,000 to 39,999, and over 40,000 head, respectively. Jones and Wiegmann (1969) estimated total cost per pound of gain in Louisiana at 23.95 to 22.93 cents when the feedlot ranged from 600- to 2,400-head capacity and was maintained at 100% capacity.

Procedure

The data reported were collected on 740 steers fed 64 rations during 14 feedlot trials at the Rice Experiment Station, Crowley, Louisiana. The breakdown of the rations in each trial and the steers per ration are shown in Table 1. The data in the text are reported on the basis of one steer per ration.

Table 1.—Rations fed in each trial and steers per ration

Trial no.	Ration no.	Steers per ration
1	6, 25	12
2	33, 34, 35, 46	8
3	27, 28	8
4	3, 8, 24, 26	14
5	1, 29, 30, 31, 49, 50, 61, 63	16
6	2, 23, 32, 47, 48, 51, 62, 64	16
7	16, 17, 18, 19, 20, 36, 37, 38, 39, 40	6
8	41, 42, 43, 44	12
9	10, 15	24
10	22, 52, 54, 56	10
11	21, 53, 55, 57, 58, 59, 60	8
12	4, 5, 7, 11, 12, 13	8
13	9, 14	24
14	45	8

Feed ingredients and pasture costs used in calculating ration costs (cost per hundredweight of feed), total feed cost, and cost per pound of gain are presented in Table 2. The costs of grain sorghum and rice bran were varied to determine the influence on cost per pound of gain.

Steers used in these trials were considered average good quality. Initial steer cost was calculated on the basis of the August 29, 1969, *Texas Livestock Market News*. Some extrapolating was necessary to arrive at the price per pound in the weight categories that were used. The price per hundredweight in the different weight ranges is shown in Table 3. At the end of each trial, the steers were slaughtered and the carcasses graded according to USDA standards. The carcass value was determined by weight and grade using the prices quoted in the August 29, 1969, *Texas Livestock Market News* for the Dallas-Fort Worth area. These prices are also shown in Table 3.

Table 2.—Feed and pasture costs used in calculating ration cost

Item	Unit	Cost (dollars)
Concentrate		
Molasses	cwt.	1.25
Grain sorghum	cwt.	2.50
Soybean meal (50%)	cwt.	5.88
Rice bran	cwt.	1.75
Cottonseed meal	cwt.	4.15
Urea	cwt.	4.50
Corn	cwt.	2.60
Oats	cwt.	3.00
Minerals		
Salt, trace mineral	cwt.	2.06
Defluorinated phosphate	cwt.	4.70
Feed additives		
Vitamin A	million IU	0.06
Terramycin	100 gm.	4.80
Roughage		
Sudangrass hay	cwt.	1.25
Alfalfa hay	cwt.	2.25
Lespedeza hay	cwt.	1.50
Rice straw	cwt.	1.00
Dehydrated pellets		
Sudangrass	cwt.	2.13
Ryegrass	cwt.	2.13
Polyethylene pellets	cwt.	1.00
Rice hulls	cwt.	0.00
Ammoniated rice hulls	cwt.	0.90
Oyster shell, pullet size	cwt.	1.77
Ryegrass pasture	acre	27.00

Table 3.—Price per hundredweight used to determine initial steer cost and gross carcass value[1]

Dollars per cwt.	Feeder steer, live weight, pounds	Carcass weight, pounds
29.25	375-400	———
28.75	400-450	———
28.25	450-500	———
27.75	500-550	———
27.25	550-615	———
52.50 - good	———	300-450
49.50 - good	———	450-700
52.00 - standard	———	all weights

[1] Based on August 29, 1969, *Texas Livestock Market News* with some extrapolating to give the liveweight categories that were used. Carcass prices from the Dallas-Ft.Worth area.

Results and Discussion

The composition of rations containing approximately 20% rice straw and the performance and returns for steers fed these rations are shown in Table 4. Feed costs per pound of gain were lowest at 16 cents for rations 10 and 15. Ration 10 was the fourth most efficient ration in this group. This efficiency (pounds of feed per pound of gain) coupled with the 30% level of rice bran made the cost of gain very favorable. Ration 15, although not very efficient, contained 50% rice bran which accounts for the low gain cost. Rations 3, 4, 5, 9, 11, 13, 14, 16, 19, and 20 gave

Table 4.—Ration ingredients and performance data of steers fed 20% rice straw

Item	Unit	Ration number 1	2	3	4	5
		Ration				
Rice straw	percent	20.0	20.0	20.0	20.0	20.0
Grain sorghum	percent	61.4	60.0	40.0	38.0	38.0
Corn	percent	—	—	—	—	—
Oats	percent	—	—	—	—	—
Rice bran	percent	—	—	10.0	20.0	20.0
Molasses	percent	10.0	10.0	25.0	10.0	10.0
Soybean meal (50%)	percent	6.1	7.5	—	—	—
Cottonseed meal (41%)	percent	—	—	—	10.0	10.0
Urea	percent	.5	.5	3.0	—	—
Salt, trace mineral	percent	1.0	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0	1.0	.9	.9
Vitamin A	100 IU	1,000	1,000	1,000	1,000	1,000
Terramycin	100 mg.	—	—	7.5	7.9	7.5
		Performance (input-output)				
Days on feed	days	140	140	84	156	52
Initial weight	pounds	490	426	610	408	408
Total gain	pounds	351	379	213	379	318
Total feed	pounds	3,206	3,038	1,999	3,179	1,205
Feed per pound gain	pounds	9.1	8.0	9.4	8.4	8.6[1]
Gain per day	pounds	2.5	2.7	2.5	2.4	2.0[2]
Pasture	acres	—	—	—	—	1.1
Carcass weight	pounds	500	475	485	480	429
Carcass grade	USDA	Good+	Good+	Good	Good+	Good
		Performance (cost-returns)				
Initial cost of steer	dollars	138.42	122.48	166.22	117.30	117.30
Gross carcass value	dollars	247.50	235.12	240.08	237.60	225.22
Feed cost:						
Per steer	dollars	74.10	71.67	38.20	68.26	25.87
Per cwt. feed	dollars	2.31	2.36	1.91	2.15	2.15
Per pound gain	dollars	.21	.19	.18	.18	.17[3]
Returns above feed and steer costs	dollars	34.98	40.47	35.66	52.04	52.35

(Continued)

economical gains at 17 and 18 cents per pound. The higher cost of oats and corn and the 11% cottonseed meal was primarily responsible for the slightly higher cost of gain with these rations.

The difference in costs of gain for steers fed rations 4 and 13 was due to different levels of rice bran. Gains were not very efficient in the feedlot when rations 5 and 11 were fed. Also, the cost of ryegrass pasture considered in the cost of gain reflects the lower gains of the steers grazing for 104 days prior to receiving ration 11 for 52 days. Feed costs per pound of gain were highest on rations 7 and 12. Although the ration costs were

Table 4 (Continued).—

Item	Unit	Ration number				
		6	7	8	9	10
		Ration				
Rice straw	percent	20.0	20.0	20.0	20.0	20.0
Grain sorghum	percent	38.0	38.0	32.0	29.3	29.4
Corn	percent	—	—	—	—	—
Oats	percent	—	—	—	—	—
Rice bran	percent	—	20.0	10.0	30.0	30.0
Molasses	percent	25.0	10.0	25.0	10.0	10.0
Soybean meal (50%)	percent	15.0	—	10.0	—	—
Cottonseed meal (41%)	percent	—	10.0	—	8.6	8.6
Urea	percent	—	—	1.0	—	—
Salt, trace mineral	percent	1.0	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	1.0	.9	1.0	1.0	1.0
Vitamin A	100 IU	1,000	1,000	1,000	1,000	—
Terramycin	100 mg.	—	7.5	7.5	7.5	—
		Performance (input-output)				
Days on feed	days	126	104	84	90	92
Initial weight	pounds	501	408	612	473	430
Total gain	pounds	343	337	252	230	222
Total feed	pounds	3,049	2,223	2,218	1,948	1,730
Feed per pound gain	pounds	8.9	7.6[1]	8.8	8.5	7.8
Gain per day	pounds	2.7	2.2[4]	3.0	2.6	2.4
Pasture	acres	—	1.1	—	—	—
Carcass weight	pounds	493	454	512	404	368
Carcass grade	USDA	Good+	Good—	Good+	Good	Stand.
		Performance (cost-returns)				
Initial cost of steer	dollars	139.03	117.30	166.77	133.62	123.62
Gross carcass value	dollars	244.04	224.73	253.44	212.10	191.36
Feed cost:						
Per steer	dollars	73.78	47.73	48.96	39.96	34.76
Per cwt. feed	dollars	2.42	2.15	2.21	2.05	2.01
Per pound gain	dollars	.22	.23[3]	.19	.17	.16
Returns above feed and steer costs	dollars	31.23	30.00	37.71	38.52	32.98

(Continued)

$2.15 per hundredweight for rations 4, 5, and 7, and $2.07 per hundredweight for rations 11, 12, and 13, the feed costs of gain were higher with rations 7 and 12 because the cost of ryegrass pasture was considered even though it was grazed only 52 days.

Ration 9, which was the same as ration 10, was much less efficient; therefore, cost of gain was higher. This may have been the result of more fat on the steers fed ration 9, as they graded slightly higher. Ration 14 contained 10% more rice bran than ration 9. This lowered ration

Table 4 (Continued).—

Item	Unit	Ration number 11	12	13	14	15
		— — — — — — — — — Ration — — — — — — — —				
Rice straw	percent	20.0	20.0	20.0	20.0	20.0
Grain sorghum	percent	28.0	28.0	28.0	19.3	9.4
Corn	percent	—	—	—	—	—
Oats	percent	—	—	—	—	—
Rice bran	percent	30.0	30.0	30.0	40.0	50.0
Molasses	percent	10.0	10.0	10.0	10.0	10.0
Soybean meal (50%)	percent	—	—	—	—	—
Cottonseed meal (41%)	percent	10.0	10.0	10.0	8.6	8.6
Urea	percent	—	—	—	—	—
Salt, trace mineral	percent	1.0	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	.9	.9	.9	1.0	1.0
Vitamin A	100 IU	1,000	1,000	1,000	1,000	—
Terramycin	100 mg.	7.5	7.5	7.5	7.5	—
		— — — — — Performance (input-output) — — — — —				
Days on feed	days	52	104	156	90	92
Initial weight	pounds	408	408	408	481	430
Total gain	pounds	300	310	368	205	193
Total feed	pounds	1,179	2,379	3,086	1,893	1,674
Feed per pound gain	pounds	8.7[1]	9.0[1]	8.4	9.2	8.7
Gain per day	pounds	1.9[2]	2.0[4]	2.4	2.3	2.1
Pasture	acres	1.1	1.1	—	—	—
Carcass weight	pounds	410	426	461	394	343
Carcass grade	USDA	Good	Good—	Good	Good	Stand.+
		— — — — — Performance (cost-returns) — — — — —				
Initial cost of steer	dollars	117.30	117.30	117.30	135.88	123.62
Gross carcass value	dollars	215.25	223.65	228.20	206.85	178.36
Feed costs:						
Per steer	dollars	24.42	49.29	63.94	37.41	31.13
Per cwt. feed	dollars	2.07	2.07	2.07	1.98	1.86
Per pound gain	dollars	.18[3]	.25[3]	.17	.18	.16
Returns above feed and steer costs	dollars	43.83	27.36	46.96	33.56	23.61

(Continued)

costs and efficiency. Also, steers fed ration 12 did not convert the feed very efficiently. The cost of ration 3 was low due to the high level of molasses and urea and the absence of natural protein; however, this ration was not efficient.

Table 4 (Continued).—

Item	Unit	Ration number				
		16	17	18	19	20
— — — — — — — — — Ration — — — — — — — — —						
Rice straw	percent	22.0	22.2	20.8	21.5	21.1
Grain sorghum	percent	—	—	—	—	—
Corn	percent	19.4	49.0	42.0	34.8	27.0
Oats	percent	7.8	7.8	7.9	7.8	7.9
Rice bran	percent	31.2	—	7.9	15.7	23.7
Molasses	percent	7.8	7.8	7.9	7.8	7.9
Soybean meal (50%)	percent	—	—	—	—	—
Cottonseed meal (41%)	percent	11.0	12.4	12.7	11.5	11.5
Urea	percent	—	—	—	—	—
Salt, trace mineral	percent	1.0	.8	.8	.8	.8
Defluorinated phosphate	percent	—	—	—	—	—
Vitamin A	100 IU	—	—	—	—	—
Terramycin	100 mg.	—	—	—	—	—
— — — — — Performance (input-output) — — — — —						
Days on feed	days	160	160	160	160	160
Initial weight	pounds	405	388	440	382	438
Total gain	pounds	296	290	309	347	326
Total feed	pounds	2,544	2,528	2,688	2,608	2,656
Feed per pound gain	pounds	8.6	8.7	8.7	7.5	8.1
Gain per day	pounds	1.8	1.8	1.9	2.2	2.0
Pasture	acres	—	—	—	—	—
Carcass weight	pounds	386	377	413	403	424
Carcass grade	USDA	Stand.+	Stand.+	Stand.+	Stand.+	Stand.+
— — — — — — Performance (cost-returns) — — — — — —						
Initial cost of steer	dollars	116.44	113.49	126.50	111.74	125.92
Gross carcass value	dollars	200.72	196.04	214.76	209.56	220.48
Feed cost:						
Per steer	dollars	52.78	59.67	62.26	57.98	57.45
Per cwt. feed	dollars	2.07	2.36	2.32	2.22	2.16
Per pound gain	dollars	.18	.21	.20	.17	.18
Returns above feed and steer costs	dollars	31.50	22.88	26.00	39.84	37.11

[1] Feed per pound of gain based on feedlot gain only.

[2] Average gain from 52 days on feed and 104 days on ryegrass pasture.

[3] Including cost of 1.1 acre ryegrass at $29.70.

[4] Average gain from 104 days on feed and 52 days on ryegrass pasture.

The composition of rations containing various levels of rice straw and the performance and returns for steers fed these rations are shown in Table 5. Rations 21, 22, 23, 24, 25, and 26 contained 40% rice straw with feed costs per pound of gain ranging from 18 to 24 cents. Feed costs per pound of gain were lowest on ration 24 where the ration contained 10% rice bran, 25% molasses, and 3% urea. Replacing 66% of the urea with soybean meal (50%) in ration 26 increased the feed cost per pound of gain to 22 cents, even though feed conversion was improved only slightly. Feed cost per pound of gain was 23 cents in ration 25 where rice bran

Table 5.—Ration ingredients and performance data of steers fed various rice straw rations

		Ration number				
Item	Unit	21	22	23	24	25
		Ration				
Rice straw	percent	40.0	40.0	40.0	40.0	40.0
Grain sorghum	percent	38.3	38.3	37.0	20.0	15.0
Rice bran	percent	—	—	—	10.0	—
Molasses	percent	4.0	4.0	10.0	25.0	25.0
Soybean meal (50%)	percent	16.6	16.6	10.5	—	18.0
Urea	percent	—	—	.5	3.0	—
Salt, trace mineral	percent	.5	.5	1.0	1.0	1.0
Defluorinated phosphate	percent	.5	.5	1.0	1.0	1.0
Vitamin A	100 IU	1,000	1,000	1,000	1,000	1,000
Terramycin	100 mg.	7.5	7.5	7.5	7.5	—
		Performance (input-output)				
Days on feed	days	140	140	140	84	126
Initial weight	pounds	452	523	426	610	510
Total gain	pounds	283	319	337	181	306
Total feed	pounds	2,811	3,147	3,192	2,041	3,213
Feed per pound gain	pounds	9.9	9.9	9.5	11.3	10.5
Gain per day	pounds	2.0	2.3	2.4	2.2	2.4
Carcass weight	pounds	408	498	434	442	460
Carcass grade	USDA	Good	Good	Good	Good	Good
		Performance (cost-returns)				
Initial cost of steer	dollars	127.69	145.13	122.48	166.22	141.52
Gross carcass value	dollars	214.20	246.51	227.85	232.05	227.70
Feed cost:						
Per steer	dollars	68.88	77.09	68.97	32.84	71.33
Per cwt. feed	dollars	2.45	2.45	2.16	1.61	2.22
Per pound gain	dollars	.24	.24	.20	.18	.23
Returns above feed and steer costs	dollars	17.63	24.29	36.40	32.99	14.65

(Continued)

and urea were not included. When urea and rice bran were deleted and molasses reduced to 4% in rations 21 and 22, feed costs per pound were higher at 24 cents.

Rations 27 and 28 contained 60% rice straw and could be used for wintering or growing cattle. Costs of feed per pound of gain were 19 and 23 cents for rations 27 and 28, respectively. The latter was more efficient, but ration cost was lower for the former and overcame the disadvantage of inefficiency. The lower cost of ration 27 was due to the use of urea as a protein substitute. The cost per pound of gain was also 19 cents for ration 29, which contained only 5% rice straw. Ration 29 was more efficient than ration 27 because of a lower roughage level, which resulted in a higher ration cost ($1.07 more per hundredweight) than ration 27.

Table 5 (Continued).—

		Ration number			
Item	Unit	26	27	28	29
— — — Ration — — —					
Rice straw	percent	40.0	60.0	60.0	5.0
Grain sorghum	percent	9.0	13.5	—	77.8
Rice bran	percent	10.0	—	—	—
Molasses	percent	25.0	22.0	22.0	10.0
Soybean meal (50%)	percent	13.0	—	16.0	4.7
Urea	percent	1.0	2.5	—	.5
Salt, trace mineral	percent	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0	1.0	1.0
Vitamin A	100 IU	1,000	1,000	1,000	1,000
Terramycin	100 mg.	7.5	7.5	7.5	—
— — — Performance (input-output) — — —					
Days on feed	days	84	196	196	140
Initial weight	pounds	612	413	411	490
Total gain	pounds	218	312	368	337
Total feed	pounds	2,352	4,273	4,390	2,604
Feed per pound gain	pounds	10.8	13.7	11.9	7.7
Gain per day	pounds	2.6	1.6	1.9	2.4
Carcass weight	pounds	471	371	409	485
Carcass grade	USDA	Good	Good	Good	Good+
— — — Performance (cost-returns) — — —					
Initial cost of steer	dollars	166.77	118.74	118.16	138.42
Gross carcass value	dollars	233.14	194.78	214.72	240.08
Feed cost:					
Per steer	dollars	47.25	60.80	84.02	64.81
Per cwt. feed	dollars	2.01	1.42	1.91	2.49
Per pound gain	dollars	.22	.19	.23	.19
Returns above feed and steer costs	dollars	19.12	15.24	12.54	36.85

Composition of rations containing rice hulls and the performance and returns for steers fed these rations are shown in Table 6. Ration 30 contained only 5% rice hulls; therefore, ration cost per hundredweight was highest. However, feed conversion was good, resulting in a feed cost per pound of gain of 18 cents. Rations 31, 32, and 34, containing 20% rice hulls, differed only slightly in composition or ration costs. Therefore, the higher feed cost per pound of gain for ration 31 was attributed to the low feed conversion of steers on this ration. This low feed conversion is without explanation. More soybean meal (50%) was used in ration 33 to increase the crude protein level; therefore, the ration cost was increased. This along with the inefficiency, due to the low gain, of steers on this ration, resulted in a feed cost per pound of gain of 21 cents. Ration 35 was similar in composition to ration 34 with the exception of am-

Table 6.—Ration ingredients and performance data of steers fed rice hull rations

Item	Unit	Ration number					
		30	31	32	33	34	35
— — — — — — — — Ration — — — — — — — —							
Rice hulls	percent	5.0	20.0	20.0	20.0	20.0	—
Ammoniated rice hulls	percent	—	—	—	—	—	20.0
Grain sorghum	percent	77.5	60.0	59.0	55.5	59.5	59.5
Soybean meal (50%)	percent	5.0	7.5	8.5	12.5	8.5	8.5
Molasses	percent	10.0	10.0	10.0	10.0	10.0	10.0
Urea	percent	.5	.5	.5	—	—	—
Salt, trace mineral	percent	1.0	1.0	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0	1.0	.9	.9	.9
Vitamin A	100 IU	1,000	1,000	1,000	1,000	1,000	1,000
Terramycin	100 mg.	—	—	—	7.5	7.5	7.5
— — — — — Performance (input-output) — — — — —							
Days on feed	days	140	140	140	168	168	168
Initial weight	pounds	490	490	426	436	435	436
Total gain	pounds	305	255	315	289	319	336
Total feed	pounds	2,268	2,212	2,380	2,551	2,434	2,735
Feed per pound gain	pounds	7.4	8.7	7.6	8.8	7.6	8.1
Gain per day	pounds	2.2	1.8	2.2	1.7	1.9	2.0
Carcass weight	pounds	472	419	429	439	445	471
Carcass grade	USDA	Good+	Good	Good	Good	Good	Good+
— — — — — Performance (cost-returns) — — — — —							
Initial cost of steer	dollars	138.42	138.42	122.48	125.35	125.06	125.35
Gross carcass value	dollars	233.64	219.98	225.22	230.48	233.62	233.14
Feed cost:							
Per steer	dollars	55.55	47.75	52.19	60.11	54.03	65.64
Per cwt. feed	dollars	2.45	2.16	2.19	2.36	2.22	2.40
Per pound gain	dollars	.18	.19	.17	.21	.17	.20
Returns above feed and steer costs	dollars	39.67	33.81	50.55	45.02	54.53	42.15

moniated rice hulls used in the former. The ammoniated rice hulls increased ration cost and decreased efficiency slightly, resulting in a feed cost of 20 cents per pound of gain.

The composition of rations containing approximately 20% lespedeza hay and the performance and returns for steers fed these rations are shown in Table 7. The only important difference in the composition of rations 36, 37, 38, 39, and 40 was the level of rice bran, which ranged from 0 to 31.6%. This was reflected in the ration cost which decreased as the level of rice bran increased. Feed cost per pound of gain was highest (20 cents) when steers were fed ration 36 and lowest (17 cents) when steers were fed ration 40. Feed costs per pound of gain for rations 37, 38, and 39 were intermediate to rations 36 and 40. There is no apparent explanation for the difference in feed conversion of these rations. The lespedeza hay and concentrate were hand-fed separately.

Table 7.—Ration ingredients and performance data of steers fed 20% lespedeza hay ration

Item	Unit	Ration number				
		36	37	38	39	40
		— — — — — — — — — Ration — — — — — — — —				
Lespedeza hay	percent	20.1	21.6	21.0	21.6	21.1
Corn	percent	50.3	41.6	35.0	26.8	19.6
Oats	percent	8.0	7.8	7.9	7.8	7.8
Cottonseed meal (41%)	percent	12.8	12.6	11.6	11.6	11.1
Molasses	percent	8.0	7.8	7.9	7.8	7.9
Rice bran	percent	——	7.8	15.8	23.6	31.6
Salt, trace mineral	percent	.8	.8	.8	.8	.8
		— — — — — — Performance (input-output) — — — — —				
Days on feed	days	160	160	160	160	160
Initial weight	pounds	447	375	428	389	437
Total gain	pounds	339	336	338	317	346
Total feed	pounds	2,768	2,608	2,672	2,608	2,656
Feed per pound gain	pounds	8.2	7.8	7.9	8.2	7.7
Gain per day	pounds	2.1	2.1	2.1	2.0	2.2
Carcass weight	pounds	439	407	429	402	425
Carcass grade	USDA	Stand.+	Stand.+	Stand.+	Stand.+	Stand.+
		— — — — — — Performance (cost-returns) — — — — —				
Initial cost of steer	dollars	128.51	109.69	123.05	113.78	125.64
Gross carcass value	dollars	228.28	211.64	223.08	209.04	221.00
Feed cost:						
Per steer	dollars	69.08	62.93	62.41	59.07	58.15
Per cwt. feed	dollars	2.50	2.41	2.34	2.26	2.19
Per pound gain	dollars	.20	.19	.18	.19	.17
Returns above feed and steer costs	dollars	30.69	39.02	37.62	36.19	37.21

The composition of rations containing approximately 30% lespedeza hay and the performance and returns for steers fed these rations are presented in Table 8. Rations 41, 42, 43, and 44 increased in rice bran content from 0 to 21.1%. Ration cost per hundredweight decreased as the level of rice bran increased. Exceptionally inefficient feed conversions resulted in high feed costs per pound of gain. The lespedeza hay and concentrate portion of the rations were hand-fed daily, which may have contributed to the poor performance of these steers.

Table 8.—Ration ingredients and performance data of steers fed 30% lespedeza hay

Item	Unit	Ration number 41	42	43	44
		— — — — Ration — — — —			
Lespedeza hay	percent	29.4	30.2	29.9	29.7
Grain sorghum	percent	58.5	50.7	43.9	37.0
Soybean meal (50%)	percent	2.5	2.6	2.7	2.7
Molasses	percent	7.1	7.0	7.0	7.0
Rice bran	percent	——	7.0	14.0	21.1
Urea	percent	.7	.7	.7	.7
Salt, trace mineral	percent	.9	.9	.9	.9
Defluorinated phosphate	percent	.9	.9	.9	.9
		— — — Performance (input-output) — — —			
Days on feed	days	87	87	87	87
Initial weight	pounds	526	535	522	535
Total gain	pounds	174	163	166	187
Total feed	pounds	1,775	1,723	1,740	1,757
Feed per pound gain	pounds	10.2	10.6	10.5	9.4
Gain per day	pounds	2.0	1.9	1.9	2.1
Carcass weight	pounds	424	426	419	447
Carcass grade	USDA	Stand.+	Stand.+	Stand.+	Stand.+
		— — — Performance (cost-returns) — — —			
Initial cost of steer	dollars	145.96	148.46	144.86	148.46
Gross carcass value	dollars	220.48	221.52	217.88	232.44
Feed cost:					
Per steer	dollars	39.64	37.44	37.01	36.53
Per cwt. feed	dollars	2.23	2.17	2.13	2.08
Per pound gain	dollars	.23	.23	.22	.20
Returns above feed and steer costs	dollars	34.88	35.62	36.01	47.45

The composition of rations containing sudangrass hay and the performance and returns for steers fed the rations are shown in Table 9. Feed costs per pound of gain were high on rations 45 and 46 at 25 and 21 cents, respectively. Ration 45 was very inefficient, requiring 12.2 pounds of feed per pound of gain. This was due to the 40% level of sudangrass hay. This could be considered a wintering type ration. Ration 46 with 20% sudangrass hay was more efficient, but still not satisfactory in this respect. The cost of sudangrass hay and soybean meal (50%) resulted in a high ration cost, which when coupled with the poor feed conversion resulted in a high cost per pound of gain.

Table 9.—Ration ingredients and performance data of steers fed sudangrass hay

Item	Unit	Ration number 45	Ration number 46
	— — — Ration — — —		
Sudangrass hay	percent	40.0	20.0
Grain sorghum	percent	50.2	58.1
Soybean meal (50%)	percent	2.8	9.9
Molasses	percent	5.0	10.0
Salt, trace mineral	percent	1.0	1.0
Defluorinated phosphate	percent	.9	.9
Vitamin A	100 IU	1,000	1,000
Terramycin	100 mg.	7.5	7.5
	— — — Performance (input-output) — — —		
Days on feed	days	84	168
Initial weight	pounds	514	436
Total gain	pounds	139	348
Total feed	pounds	1,695	2,954
Feed per pound gain	pounds	12.2	8.5
Gain per day	pounds	1.7	2.1
Carcass weight	pounds	365	490
Carcass grade	USDA	Stand.+	Good+
	— — — Performance (cost-returns) — — —		
Initial cost of steer	dollars	142.64	125.35
Gross carcass value	dollars	189.80	242.55
Feed cost:			
Per steer	dollars	35.43	74.44
Per cwt. feed	dollars	2.09	2.52
Per pound gain	dollars	.25	.21
Returns above feed and steer costs	dollars	11.73	42.76

The composition of rations containing alfalfa hay, and the performance and returns for steers fed these rations, are shown in Table 10. Gains were similar on all rations regardless of the level of alfalfa hay. An 18 cent feed cost per pound of gain on rations 48, 49, and 50 was not excessive, especially when the cost of alfalfa increased the ration cost. Ration 47, which contained 40% alfalfa hay, was less efficient. Therefore, the feed cost per pound of gain was increased to 20 cents.

The composition of rations containing dehydrated forage pellets and the performance and returns for steers fed these rations are shown in Table 11. The cost of the dehydrated forage pellets was only slightly lower than the cost of grain sorghum; therefore, the ration cost was high. Also, the low crude protein content of the sudangrass pellets made it necessary to add more soybean meal (50%) to the ration, which increased the cost. Feed costs per pound of gain ranged from 22 to 25 cents in

Table 10.—Ration ingredients and performance data of steers fed alfalfa hay rations

Item	Unit	Ration number 47	48	49	50
— — — — — — — — Ration — — — — — — — —					
Alfalfa hay	percent	40.0	20.0	20.0	5.0
Grain sorghum	percent	47.5	65.0	67.5	79.5
Soybean meal (50%)	percent	——	2.0	——	3.0
Molasses	percent	10.0	10.0	10.0	10.0
Urea	percent	.5	.5	.5	.5
Salt, trace minerals	percent	1.0	1.0	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0	1.0	1.0
Vitamin A	100 IU	1,000	1,000	1,000	1,000
— — — — — Performance (input-output) — — — — —					
Days on feed	days	140	140	140	140
Initial weight	pounds	426	425	490	490
Total gain	pounds	302	308	312	322
Total feed	pounds	2,562	2,310	2,422	2,380
Feed per pound gain	pounds	8.5	7.5	7.8	7.4
Gain per day	pounds	2.2	2.2	2.2	2.3
Carcass weight	pounds	437	432	465	478
Carcass grade	USDA	Good	Good	Good+	Good
— — — — — Performance (cost-returns) — — — — —					
Initial cost of steer	dollars	122.48	122.19	138.42	138.42
Gross carcass value	dollars	229.42	226.80	230.18	236.61
Feed cost:					
Per steer	dollars	59.07	56.36	57.05	57.37
Per cwt. feed	dollars	2.31	2.44	2.35	2.49
Per pound gain	dollars	.20	.18	.18	.18
Returns above feed and steer costs	dollars	47.87	48.24	34.78	38.82

rations 51, 52, 53, 54, 55, 56, and 57, which contained dehydrated sudangrass pellets. The cost of feed required to produce a pound of gain decreased to 19 cents in ration 58 and to 20 cents in rations 59 and 60, which contained 40, 60, and 80% dehydrated ryegrass pellets, respectively. Feed efficiency decreased as the level of ryegrass pellets increased, but because of the crude protein content of the pellets the addition of soybean meal (50%) was decreased.

Table 11.—Ration ingredients and performance data of steers fed dehydrated forage pellet rations

Item	Unit	Ration number				
		51	52	53	54	55
— — — — — — — — — Ration — — — — — — — — —						
Dehydrated sudangrass pellets	percent	40.0	40.0	40.0	60.0	60.0
Dehydrated ryegrass pellets	percent	——	——	——	——	——
Grain sorghum	percent	42.0	45.9	45.9	25.4	25.4
Soybean meal (50%)	percent	5.5	9.0	9.0	9.5	9.5
Molasses	percent	10.0	4.0	4.0	4.0	4.0
Urea	percent	.5	——	——	——	——
Salt, trace mineral	percent	1.0	.5	.5	.5	.5
Defluorinated phosphate	percent	1.0	.5	.5	.5	.5
Vitamin A	100 IU	1,000	1,000	1,000	1,000	1,000
Terramycin	100 mg.	——	7.5	7.5	7.5	7.5
— — — — — Performance (input-output) — — — — —						
Days on feed	days	140	140	140	140	140
Initial weight	pounds	426	523	451	523	451
Total gain	pounds	328	329	321	316	325
Total feed	pounds	2,968	2,993	2,685	2,769	2,727
Feed per pound gain	pounds	9.0	9.1	8.4	8.8	8.4
Gain per day	pounds	2.3	2.4	2.3	2.3	2.3
Carcass weight	pounds	443	504	431	505	430
Carcass grade	USDA	Good+	Good	Good	Good	Good+
— — — — — Performance (cost-returns) — — — — —						
Initial cost of steer	dollars	122.48	145.13	127.41	145.13	127.41
Gross carcass value	dollars	232.58	249.48	226.28	249.98	225.75
Feed cost:						
Per steer	dollars	72.52	79.10	71.02	71.68	70.56
Per cwt. feed	dollars	2.44	2.64	2.65	2.59	2.59
Per pound gain	dollars	.22	.24	.22	.23	.22
Returns above feed and steer costs	dollars	37.58	25.25	27.85	33.17	27.78

(Continued)

Table 11 (Continued).—

Item	Unit	Ration number 56	57	58	59	60
— — — Ration — — —						
Dehydrated sudangrass pellets	percent	80.0	80.0	—	—	—
Dehydrated ryegrass pellets	percent	—	—	40.0	60.0	80.0
Grain sorghum	percent	4.9	4.9	50.9	32.9	14.9
Soybean meal (50%)	percent	10.0	10.0	4.0	2.0	—
Molasses	percent	4.0	4.0	4.0	4.0	4.0
Urea	percent	—	—	—	—	—
Salt, trace mineral	percent	.5	.5	.5	.5	.5
Defluorinated phosphate	percent	.5	.5	.5	.5	.5
Vitamin A	100 IU	1,000	1,000	1,000	1,000	1,000
Terramycin	100 mg.	7.5	7.5	7.5	7.5	7.5
— — — Performance (input-output) — — —						
Days on feed	days	140	140	140	140	140
Initial weight	pounds	524	451	451	451	452
Total gain	pounds	301	298	307	312	280
Total feed	pounds	2,979	2,671	2,378	2,629	2,573
Feed per pound gain	pounds	9.9	9.0	7.7	8.4	9.2
Gain per day	pounds	2.2	2.1	2.2	2.2	2.0
Carcass weight	pounds	478	383	428	420	393
Carcass grade	USDA	Stand.+	Good—	Good	Good	Good+
— — — Performance (cost-returns) — — —						
Initial cost of steer	dollars	145.41	127.41	127.41	127.41	127.69
Gross carcass value	dollars	248.56	201.08	224.70	220.50	206.32
Feed cost:						
Per steer	dollars	75.40	68.87	58.86	61.38	56.43
Per cwt. feed	dollars	2.53	2.58	2.48	2.33	2.19
Per pound gain	dollars	.25	.23	.19	.20	.20
Returns above feed and steer costs	dollars	27.75	4.80	38.43	31.71	22.20

The ingredient composition of rations containing artificial roughage and the performance and returns for steers fed these rations are given in Table 12. Ration 61 contained only 5% oyster shell as roughage; therefore, the ration cost was high. The poor feed conversion on this high-energy ration resulted in high feed costs per pound of gain. Ration 62 contained 20% polyethylene pellets as roughage. The polyethylene pellets had a very adverse influence on feed conversion; therefore, the feed cost per pound of gain was 24 cents.

Table 12.—Ration ingredients and performance data of steers fed artificial roughage

		Ration number	
Item	Unit	61	62
		Ration	
Oyster shell	percent	5.0	—
Polyethylene pellets	percent	—	20.0
Grain sorghum	percent	77.2	58.0
Soybean meal (50%)	percent	5.3	9.5
Molasses	percent	10.0	10.0
Urea	percent	.5	.5
Salt, trace mineral	percent	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0
Vitamin A	100 IU	1,000	1,000
		Performance (input-output)	
Days on feed	days	140	140
Initial weight	pounds	490	426
Total gain	pounds	253	259
Total feed	pounds	2,128	2,534
Feed per pound gain	pounds	8.4	9.8
Gain per day	pounds	1.8	1.8
Carcass weight	pounds	416	391
Carcass grade	USDA	Good+	Good+
		Performance (cost-returns)	
Initial cost of steer	dollars	138.42	122.48
Gross carcass value	dollars	218.40	205.28
Feed cost:			
Per steer	dollars	54.22	61.49
Per cwt. feed	dollars	2.55	2.43
Per pound gain	dollars	.21	.24
Returns above feed and steer costs	dollars	25.76	21.31

The ingredient composition of all-concentrate rations and the performance and returns for steers fed these rations are shown in Table 13. Ration 63 contained less soybean meal (50%) than ration 64; therefore, the ration cost was less. It is not clear whether the increased crude protein level increased feed efficiency of ration 64, but the difference in conversion reduced the feed cost per pound of gain from 20 cents for ration 63 to 18 cents for ration 64.

An attempt has been made to clarify differences in the feed cost of a pound of gain within each roughage group. In some instances this was not possible. Some rations, with the same ingredient composition, were not utilized with equal efficiency. Different lots of ingredients may have had an influence on efficiency. It should be pointed out that these rations were fed in different experiments, and that different breeds and weights of steers were fed for different lengths of time.

Table 13.—Ration ingredients and performance data of steers fed all concentrate rations

Item	Unit	Ration number 63	64
	Ration		
Grain sorghum	percent	83.3	78.0
Soybean meal (50%)	percent	4.2	9.5
Molasses	percent	10.0	10.0
Urea	percent	.5	.5
Salt, trace mineral	percent	1.0	1.0
Defluorinated phosphate	percent	1.0	1.0
Vitamin A	100 IU	1,000	1,000
	Performance (input-output)		
Days on feed	days	140	140
Initial weight	pounds	490	426
Total gain	pounds	295	302
Total feed	pounds	2,296	1,988
Feed per pound gain	pounds	7.8	6.6
Gain per day	pounds	2.1	2.2
Carcass weight	pounds	460	441
Carcass grade	USDA	Good+	Good+
	Performance (cost-returns)		
Initial cost of steer	dollars	138.42	122.48
Gross carcass value	dollars	227.70	231.52
Feed cost:			
Per steer	dollars	58.49	54.21
Per cwt. feed	dollars	2.55	2.73
Per pound gain	dollars	.20	.18
Returns above feed and steer costs	dollars	30.79	54.83

The feed cost ranged from 16 to 25 cents per pound of gain. Only two or three rations were in each of the extreme costs. There were 22 of the 64 rations with a cost per pound of gain of 18 cents or less. These 22 rations included 12 containing approximately 20% rice straw, two with 20% alfalfa hay, two with 20% lespedeza hay, two with 20% rice hulls, one with 40% rice straw, one with 5% rice hulls, one with 5% alfalfa hay, and one with all-concentrate.

Returns above feed and steer costs ranged from $4.80 to $54.83 for rations 57 and 64, respectively. The feed costs per pound of gain were 23 and 18 cents for the respective rations. Thirty-one rations gave returns after steer and feed costs above $35, with the feed costs per pound of gain ranging from 17 to 23 cents. Only eight 20% rice straw rations with feed costs per pound of gain of 18 cents or less and two with feed costs per pound of gain of 19 cents are represented in this group. There are also four 20% lespedeza hay rations, three 30% lespedeza hay rations, three 20% rice hull rations and one ration each containing all-concentrate, 20% alfalfa hay, 40% alfalfa hay, 5% alfalfa hay, 20% sudangrass hay, 20% ammoniated rice hulls, 40% rice straw, 40% dehydrated ryegrass pellets, 40% dehydrated sudangrass pellets, 5% rice straw, and 5% rice hulls in this group. All rations in this group gave returns above $35, but not all of the feed costs per pound of gain were 19 cents or less.

Rations with low feed costs per pound of gain did not necessarily provide high returns above steer and feed costs. Rations 4 and 15 with feed costs per pound of gain of 18 and 16 cents gave considerably different returns ($52.04 compared with $23.61, respectively). This was possibly due to different lengths of feeding periods.

Returns above feed cost are influenced by the feed cost of gain, initial steer cost and carcass value. The feed cost of gain is a function of ration cost and feed efficiency. Initial steer cost is determined by the weight and grade. The feeder steers used in these experiments were considered to grade similarly. Carcass value is a function of weight and USDA grade. The length of feeding period is important as profits can be maximized by feeding longer when the feed cost per pound of gain is favorable. Carcass grade is usually increased by longer feeding periods, but the carcass may attain an undesirable weight. This should be a consideration when cattle are large at the beginning of the feeding period.

It is realized that the cost of ingredients and feeder steers and the value of the finished cattle may vary considerably from those in Tables 2 and 3, depending on the demand and supply. The data in Tables 4 through 13 are presented in a manner that will permit other prices to be used and returns calculated.

The influence of varying the price of rice bran and grain sorghum on the feed cost per hundredweight of the rations containing these ingredients is shown in Table 14. When other ration ingredients are similar, the feed cost per hundredweight will decrease as the level of rice bran is increased. It is necessary that the total ration composition be compared in

Tables 4 through 13. As an example, rations 3, 8, 24, and 26 contain 25% molasses. These rations cannot be compared directly with rations containing other levels of molasses and rice bran.

The influence that varying the price of rice bran and grain sorghum has on the feed cost per pound of gain, based on the performance of

Table 14.—Cost per hundredweight of various rice bran and grain sorghum rations with grain sorghum at four different prices and rice bran at three different prices

Price of rice bran per cwt.	Ration no.	Price of grain sorghum per cwt.				Ration no.	Price of grain sorghum per cwt.			
		2.00	2.25	2.50	2.75		2.00	2.25	2.50	2.75
		10 percent rice bran					**20 percent rice bran**			
1.25	13	1.66	1.76	1.86	1.96	44	1.78	1.88	1.97	2.06
	6	2.00	2.08	2.16	2.24	14	1.85	1.95	2.04	2.14
	24	1.46	1.51	1.56	1.61	5	1.86	1.95	2.05	2.14
	26	1.91	1.94	1.96	1.98					
	42	1.88	2.01	2.14	2.26					
	43	1.84	1.95	2.06	2.17					
1.50	13	1.68	1.78	1.88	1.98	44	1.84	1.93	2.02	2.12
	6	2.02	2.10	2.18	2.26	14	1.90	2.00	2.09	2.19
	24	1.48	1.53	1.58	1.63	5	1.91	2.00	2.10	2.19
	26	1.94	1.96	1.98	2.01					
	42	1.90	2.03	2.15	2.28					
	43	1.87	1.98	2.09	2.20					
1.75	13	1.71	1.81	1.91	2.01	44	1.89	1.98	2.08	2.17
	6	2.05	2.13	2.21	2.29	14	1.95	2.05	2.14	2.24
	24	1.51	1.56	1.61	1.66	5	1.96	2.05	2.15	2.24
	26	1.96	1.99	2.01	2.03					
	42	1.92	2.04	2.17	2.30					
	43	1.91	2.02	2.13	2.24					
		30 percent rice bran					**40 percent rice bran**			
1.25	8	1.71	1.78	1.86	1.93					
	1	1.78	1.85	1.92	1.99	2	1.69	1.73	1.78	1.82
	10	1.78	1.85	1.92	1.99					
	7	1.75	1.83	1.90	1.97	3	1.56	1.58	1.61	1.63
1.50	8	1.79	1.86	1.93	2.01					
	1	1.86	1.93	2.00	2.07	2	1.78	1.83	1.88	1.92
	10	1.86	1.93	2.00	2.07					
	7	1.83	1.90	1.98	2.05	3	1.69	1.71	1.73	1.76
1.75	8	1.86	1.94	2.01	2.08	2	1.88	1.93	1.98	2.02
	1	1.93	2.00	2.07	2.14					
	10	1.93	2.00	2.07	2.14					
	7	1.90	1.98	2.05	2.12	3	1.81	1.83	1.86	1.88

steers as reported in Tables 4 through 13, is shown in Table 15. Feed cost per pound of gain is not necessarily linear with decreases in feed cost per hundredweight. Feed efficiency also influences feed cost of gain. The same restrictions apply to comparisons made in Table 15 as in Table 14.

Table 15.—Cost per pound of gain for various rice bran and grain sorghum rations with grain sorghum at four different prices and rice bran at three different prices

Price of rice bran per cwt.	Ration no.	Price of grain sorghum per cwt.				Ration no.	Price of grain sorghum per cwt.			
		2.00	2.25	2.50	2.75		2.00	2.25	2.50	2.75
		10 percent rice bran					**20 percent rice bran**			
1.25	13	.156	.165	.174	.184	44	.168	.177	.186	.194
	6	.176	.183	.190	.197	14	.156	.164	.172	.180
	24	.164	.170	.176	.181	5	.122	.129	.135	.141
	26	.206	.209	.211	.214					
	42	.199	.212	.226	.239					
	43	.192	.204	.215	.227					
1.50	13	.158	.167	.177	.186	44	.173	.182	.190	.199
	6	.178	.185	.192	.199	14	.160	.168	.176	.184
	24	.167	.173	.178	.184	5	.126	.132	.138	.145
	26	.209	.212	.214	.217					
	42	.201	.214	.228	.241					
	43	.196	.208	.219	.231					
1.75	13	.160	.170	.179	.188	44	.178	.187	.195	.204
	6	.180	.187	.194	.201	14	.164	.172	.180	.188
	24	.170	.176	.181	.187	5	.129	.135	.142	.148
	26	.212	.214	.217	.219					
	42	.203	.216	.229	.243					
	43	.200	.211	.223	.234					
		30 percent rice bran					**40 percent rice bran**			
1.25	8	.133	.139	.145	.150					
	1	.149	.155	.161	.167	2	.155	.159	.164	.168
	10	.136	.142	.147	.152					
	7	.149	.155	.161	.168	3	.135	.138	.140	.142
1.50	8	.139	.145	.150	.156					
	1	.156	.162	.168	.174	2	.164	.168	.173	.177
	10	.142	.148	.153	.158					
	7	.155	.162	.168	.174	3	.146	.148	.150	.152
1.75	8	.145	.151	.156	.162					
	1	.162	.168	.174	.180	2	.173	.178	.182	.187
	10	.148	.153	.159	.164					
	7	.162	.168	.174	.180	3	.157	.159	.161	.163

Summary

The data reported were collected at the Rice Experiment Station, Crowley, Louisiana, on 740 steers fed 64 rations during 14 feedlot trials. Feed costs per pound of gain were lowest (16 cents) on rations 10 and 15. Both of these rations contained approximately 20% rice straw. There were 22 of the 64 rations with a cost of 18 cents or less per pound of gain. The 22 rations were represented by 12 rations containing approximately 20% rice straw, two with 20% alfalfa hay, two with 20% lespedeza hay, two with 20% rice hulls, one with 40% rice straw, one with 5% rice hulls, one with 5% alfalfa hay, and one with all-concentrate.

The inclusion of rice bran or molasses reduced the ration cost per hundredweight and gain cost. Replacing some or all of the protein concentrate with urea reduced ration cost per hundredweight and usually reduced gain cost even though feed efficiency was reduced by high levels of urea. It was not profitable to graze ryegrass for short periods (52 days) unless the pasture could be grazed by other livestock to obtain its full potential.

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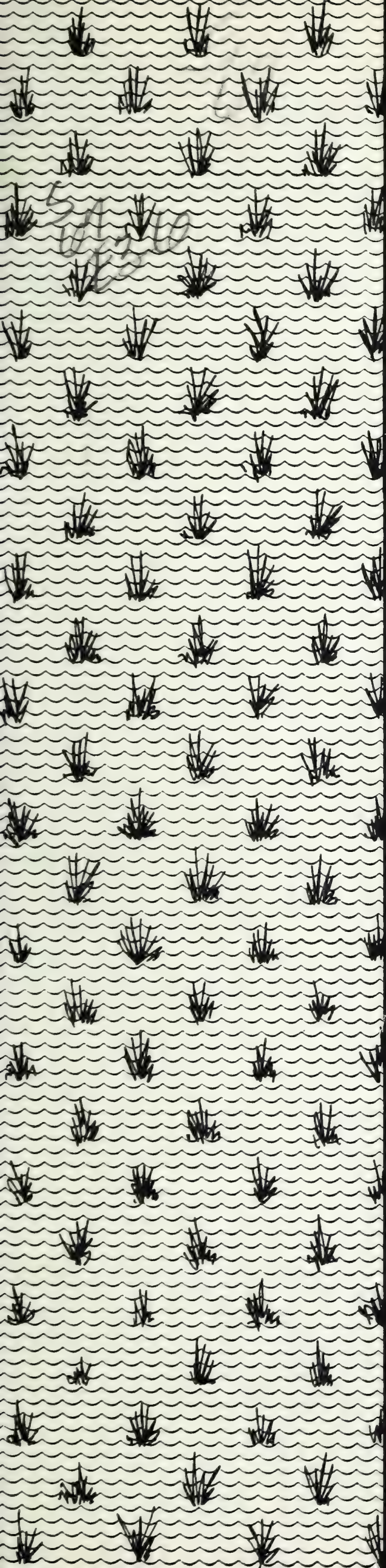
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Nitrogen Transformations in Waterlogged Soil

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Nitrogen Transformations In Waterlogged Soil

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INTRODUCTION

Nitrogen in soil undergoes many transformations. Most of these transformations are biological processes performed by microorganisms. The practical implications of these processes have promoted extensive research. A voluminous literature has accumulated, but unfortunately most of the information is limited to well-drained soils. Many of the general principles and concepts applicable to well-drained soils cannot be easily extrapolated to interpret the phenomenon of nitrogen transformation in waterlogged soils.

The special conditions prevailing under waterlogged environments lead to a considerable modification of the ammonification process and complete suppression of nitrification in zones where oxygen is not present. The breakdown of organic matter which leads to the release of ammonium ions to the soil solution proceeds at a slower rate in a waterlogged soil than in a well-drained soil (Tenny and Waksman, 1930), but the inorganic nitrogen release from decomposing rice straw, at a much wider C:N ratio, proceeds at a higher rate under waterlogged than under optimum moisture conditions (Acharya, 1935c; Sircar *et al.*, 1940). The studies of nitrogen transformation under waterlogged conditions cited here were made in the absence of soil. Further studies are needed to understand the mineralization of organic nitrogen in a waterlogged soil system. This feature of nitrogen mineralization is of great importance for the nitrogen management of rice soils.

Under waterlogged conditions, mineralization usually does not proceed beyond the ammonium stage because oxygen is necessary to carry the process through to nitrate. Nevertheless, ammonium nitrogen may be nitrified to nitrate nitrogen if it is applied to the surface oxidized layer of the soil. Nitrate nitrogen thus formed or added in the form of fertilizer is particularly subject to loss upon entry into the underlying reduced layer (Pearsall, 1950; Mitsui, 1954). Moisture fluctuations as a result of flooding and draining create ideal conditions for these losses to occur. A quantitative measurement of these losses from the applied ammonium nitrogen and native soil nitrogen is, therefore, of utmost importance for the proper utilization of applied nitrogen in rice soils.

The nature of organic nitrogen compounds occurring in waterlogged soils is poorly understood. This information is important in understanding the fate of applied nitrogen and its subsequent availability to the plant.

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The purpose of this investigation was, therefore, to study (1) the process of nitrogen transformation with special reference to the immobilization-mineralization relationship, (2) the nature, amount, and relative distribution of different chemical fractions of soil nitrogen, and (3) the fate of applied ammonium sulfate in waterlogged, anaerobic (air replaced with argon), and aerobic (optimum moisture) soil systems. Tracer techniques involving the stable isotope of nitrogen, ^{15}N, were employed to trace the path of applied nitrogen in the soil.

REVIEW OF LITERATURE

A. The Anaerobic Decomposition of Soil Organic Matter

1. General Nature and Composition of Soil Organic Matter

The organic fraction of the soil consists of a vast array of simple and complex substances. Included among the compounds are those represented by the various components of organic residues undergoing decomposition and the metabolic by-products of microorganisms utilizing organic residues as a source of energy. These diverse groups include proteins and their derivatives (amino acids, amides, amino sugars, nucleoproteins, and purine and pyrimidine bases); carbohydrates, their decomposition products, and related compounds (mono- and disaccharides, cellulose, hemicelluloses, pectins, pentosans, mannans, polyuronides, uronic acid polymers, organic acids, alcohols, hydrocarbons, and aromatic compounds); and lignins, fats, various organic phosphorous compounds, tannins, and their various decomposition products (Waksman, 1938; Broadbent, 1953; Kononova, 1961; and Stevenson, 1964). In addition to the intermediate products of decomposition and secondary products of microbial synthesis, there also exist in soil the more resistant products of decomposition (Kononova, 1961).

The decomposition of organic matter in soil is generally carried out by a wide group of heterotrophic microorganisms and is accomplished in two main steps occurring simultaneously. These steps are the breakdown of freshly added organic substances and the decomposition of the native soil organic matter or humus. Plant and animal residues added to soil are first broken down to their basic structural units by extracellular enzymes produced by heterotrophs. These units are then oxidized intracellularly by microorganisms in order to derive energy. In spite of the dissimilarity of such compounds as polysaccharides, aromatic substances, and proteins, it is important to note that, after their initial degradation by extracellular enzymes, the metabolic sequences taking place in the microbial cell follow the same general pathways in the production of energy. As a consequence of these activities, the nutrient elements carbon, nitrogen, phosphorus, and sulfur are released in forms available to plants. At the same time, however, appreciable amounts of these elements are being immobilized in the formation of new microbial tissues or metabolic by-products.

The nature of the flora involved in organic matter decomposition varies with the chemical composition of the added substrates. Certain microbial groups predominate for a short time, while others maintain high populations for a considerably longer period. Each individual organism is equipped with a complex of enzymes which permits it to oxidize a fixed array of chemical compounds. If the proper substances are present in an accessible state, the microorganism will proliferate, provided that it can withstand the competition of other organisms possessing similar enzymatic characteristics. The microorganisms preferentially proliferating on the basic components of the added carbonaceous substances constitute the primary flora. These are followed by a secondary flora growing either on compounds produced by the primary flora or on the dead or living cells of the primary flora. The secondary group of organisms possesses a different biochemical make-up from those appearing initially. The population responding to organic matter additions thus feeds upon (a) organic substrates added, (b) intermediate products formed during decomposition, and (c) protoplasm of microorganisms active in the degradation of (a) and (b) (Alexander, 1961).

Microbial studies have shown that the amount and composition of microflora are generally determined by the amount, type, and availability of organic matter. The addition of simple sugar causes rapid proliferation of bacteria, while starch accelerates the activity of actinomycetes, and cellulose benefits fungal development in particular (Alexander, 1961). Proteins and amino acids, such as blood meal or peptone, stimulate spore-forming bacilli (Winogradsky, 1924; Mollenhoff *et al.*, 1936). As a result of the development of mixed microflora on chemically complex natural products, some constituents quickly disappear while others persist. The water-soluble fraction is usually the first to be metabolized, followed by the oxidation of cellulose and hemicelluloses at approximately equal rates. The lignins are the most resistant, and consequently become abundant in the residual decaying organic matter (Alexander, 1961).

2. Anaerobic Decomposition as Compared with Aerobic Decomposition

The anaerobic decomposition of organic matter in waterlogged soils is a considerably modified process and can be differentiated from the aerobic decomposition in two important aspects: first, by its much slower rate, and second, by the nature of the end products formed.

The microbial decomposition of organic matter in a well-drained soil is accomplished by a wide group of microorganisms. The aerobic mode of respiration in these organisms is associated with high energy release. Therefore, the decomposition of substrate and synthesis of cell substances proceed at a rapid rate. As a result, most components forming the bulk of the added organic matter quickly disappear as CO_2, while those less susceptible to microbial attack persist. Concomitantly, as cell synthesis proceeds, a heavy demand is placed upon the soil nutrients. This is particularly true for nitrogen, except when highly nitrogenous materials are added.

Anaerobic decomposition, on the other hand, is almost entirely dependent on the activities of anaerobic bacteria. Facultative anaerobes may also assist in decomposition if nitrate nitrogen is present to act as an electron acceptor in their respiration. Since anaerobic bacteria operate at a much lower energy level, they are much less efficient than aerobic flora. Consequently, the processes of both decomposition and resynthesis are much slower in a waterlogged soil than in a well-drained soil. This is in agreement with the general observation that greater accumulation of plant residues occurs in bog and marsh soils.

Tenny and Waksman (1930) made a comprehensive study of the decomposition rate of various chemical constituents of a variety of plant material under both aerobic and anaerobic conditions. Their data showed that anaerobic decomposition was slower than aerobic decomposition regardless of the type of plant material used. The difference in the rates of aerobic and anaerobic decomposition of the various plant constituents was even more pronounced. This was true particularly in the case of lignins and organic nitrogenous complexes. For corn stalk rich in water-soluble substances including reducing sugars and nitrogen compounds, a comparison of decomposition rates showed that, after 27 days, 20 percent of the total material was lost under anaerobic conditions, whereas 37 percent disappeared during the same period of time in the aerobic system. After 498 days, 38 percent of the total organic matter was left in the anaerobic system as compared with only 22 percent after 405 days in the aerobic system. Even more striking differences were observed when individual chemical constituents were compared under both sets of conditions. Whereas the complex polysaccharides decomposed twice as fast under aerobic as under anaerobic conditions during the first four weeks, the lignin remained resistant to attack by microorganisms in both cases. However, when decomposition eventually began, 21 percent of the lignin disappeared in 68 days under aerobic conditions, whereas only 8 percent was lost in 135 days under anaerobic conditions. Even after a period of nearly a year and a half, less than one-third of the lignin disappeared under the most favorable temperature conditions of anaerobic decomposition.

Relatively slower rates of decomposition were observed under both aerobic and anaerobic conditions in the case of rye straw, with its lower content of soluble carbohydrates and higher lignin content. About 17 percent of the rye straw decomposed in 66 days and 29 percent in 143 days in the aerobic system, whereas under anaerobic conditions 7 and 22 percent were decomposed in 84 and 163 days, respectively. The three principal chemical constituents, cellulose, hemicellulose, and lignin, were also found to have decomposed much more slowly under anaerobic than aerobic conditions.

The difference in the rate and nature of decomposition of natural plant substances under the two sets of conditions was even more marked in the case of oak leaves. When the material was properly aerated, 42 percent of the total organic matter was decomposed in 286 days, whereas anaerobic loss was only about one-fourth of this amount. The lignin in the oak leaves did not decompose at all under the anaerobic conditions, while hemicellulose decomposed extremely slowly. A similar decomposition pattern was noted for alfalfa in spite of its relatively high nitrogen content. This indicated that even a high nitrogen content did not cause rapid decomposition under anaerobic conditions. This was true not only for the total plant material but also for the individual plant constituents.

It is noteworthy that accumulation of proteins was greater under anaerobic conditions than under aerobic conditions in all cases. This may have been due to the more economic use of nitrogen, to the smaller loss of ammonia, or to the lesser decomposition of synthesized protein in the anaerobic system.

Acharya (1935a, 1935b) demonstrated that the decomposition of rice straw was most rapid in aerobic environments, slower under waterlogged conditions, and least pronounced under complete anaerobiasis. This was equally true for the decay of major plant constituents. Further, Acharya stressed the low nitrogen demands of the anaerobic metabolism. Sircar *et al.* (1940) further confirmed the findings of Waksman and Tenny (1930), and Acharya (1935a, 1935b) regarding microbiological decomposition of plant materials. Alexander (1961) emphasized the slow rate of organic matter breakdown and resynthesis under total anaerobiasis as opposed to an environment with adequate supply of oxygen. The waterlogged soils were intermediate between the two extremes. He attributed these differences to the low energy yield of anaerobic fermentation.

The second and the most striking difference in the decomposition of organic matter under waterlogged and well-drained soil conditions lies in the nature of the end products formed. In a well-drained soil, the main end products of decomposition are carbon dioxide, nitrate, sulfate, water, and resistant residues. The waterlogged soil, on the other hand, is generally characterized by the formation of chiefly carbon dioxide, methane, hydrogen, organic acids, ammonia, amines, mercaptans, hydrogen sulfide, and resistant residues.

The metabolic degradation of carbohydrate is probably the same under both aerobic and anaerobic conditions until the formation of pyruvic acid as the final end product of glycolysis. In an aerated soil, pyruvic acid enters the Krebs cycle. This is a common channel not only for the oxidation of the products of glycolysis but also for the ultimate oxidation of the fatty acids and the carbon skeleton of many amino acids. The cycle functions to convert all of these carboxylic acids to CO_2 and H_2O in the presence of molecular oxygen through the mediation of terminal oxidases. In a waterlogged soil, marked by the virtual absence of oxygen, the terminal oxidation is suppressed, resulting in the accumulation of pyruvic acid and reduced nicotinamide-adenine dinucleotide [NADH]. The pyruvic acid in turn undergoes various transformations not specific to any organism, but presenting a common feature of anaerobic fermentation.

Some of the typical reactions pyruvic acid may undergo are as follows:

(i) Reduction to lactic acid by reduced NAD:

$$CH_3COCOOH + NADH + H^+ \rightarrow CH_3CHOHCOOH + NAD$$

(ii) Decarboxylation to acetaldehyde and subsequent reduction to ethyl alcohol:

$$CH_3COCOOH \rightarrow CH_3CHO + CO_2$$

$$CH_3CHO + NADH + H^+ \rightarrow CH_3CH_2OH + NAD$$

It is at this stage that the specificity comes in so that any further transformation may be carried out through the activities of specific bacteria. For example, *Bacillus fossicularum* is probably involved in the formation of butyric acid from lactic acid (Ponnamperuma, 1955):

$$2CH_3CHOHCOOH \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$$

Clostridium butyricum may be responsible for changing pyruvic acid to butyric acid (Barnett, 1954):

$$CH_3COCOOH \rightarrow CH_3CH_2CH_2COOH + CH_3COOH + CO_2 + H_2$$

The fermentation characteristics of microflora favor the accumulation of organic acids. In waterlogged soil, as well as in its counterpart well-drained soil, the dominant acids are usually acetic acid and formic acid (Takai and Koyama, 1956). Subrahmanyan (1929) demonstrated the presence of lactic acid, acetic, and butyric acids in the solution phase when glucose was allowed to decompose. Further, he noted that lactic acid was the first major product of anaerobic fermentation that was subsequently transferred to acetic and butyric acids.

A variety of reactions lead to the formation of methane in oxygen depleted environments. This process has been characterized in mixed population and frequently in pure culture. The following reactions are typical (Alexander, 1961):

$$\begin{aligned}
&CO_2 + 4H_2 &&\rightarrow CH_4 + 2H_20\\
&4HCOOH &&\rightarrow CH_4 + 3CO_2 + 2H_20\\
&CH_3COOH &&\rightarrow CH_4 + CO_2\\
&2CH_3CH_2OH + CO_2 &&\rightarrow 2CH_3COOH + CH_4\\
&4CH_3CH_2COOH + 2H_2O &&\rightarrow 4CH_3COOH + CO_2 + 3CH_4
\end{aligned}$$

Most of these reactions are specific. *Methanobacillus omelianskii* is probably specific for the conversion of hydrogen, ethanol, and primary and secondary alcohols to methane. *Methanobacterium propionicum* changes propionic acid to methane (Baker, 1956).

Harrison (1920) suggested that hydrogen evolution in waterlogged soils is inconsequential solely because the gas reacts with CO_2 to yield methane, a reaction which supplies the bacteria both energy and source of carbon. A number of bacteria have been isolated which can utilize H_2 for the reduction of CO_2 (Alexander, 1961).

According to Russell (1961), this reaction is of great importance for the oxygen regime of rice roots, because it not only reduces the CO_2 content in that zone but also removes H_2 in a way that makes a much lower demand on the oxygen in the soil-water than would be made by hydrogen-oxidizing bacteria, as suggested by Harrison and Aiyer (1916).

Research by Harrison and Aiyer (1913, 1915, 1916), Harrison (1920), and Aiyer (1920) explained the transformation of CH_4, CO_2, and H_2 in swamp rice soils. They observed that the principal gas produced following the addition of green manure to waterlogged soil was methane, with only small amounts of CO_2, H_2, and perhaps nitrogen. But the gas that was evolved at the surface was almost entirely oxygen and nitrogen. They attributed this to the film of microorganisms, which at the surface contained bacteria, algae, and diatoms. The bacteria oxidized hydrogen and methane to water and CO_2, respectively. The latter in turn was fixed photosynthetically by algae with the liberation of oxygen. They implied that green manuring stimulated the growth of rice through the increased oxygen content of the water percolating downward through the surface soil. An alternate implication perhaps of more economic significance may be possible. The increased oxygen content at the surface may induce oxidation of surface applied ammonium fertilizer, resulting in the formation of nitrates. The nitrate thus formed may move down into the anaerobic zone and subsequently be denitrified.

Acharya (1935a, 1935b, 1935c) examined in detail the course of anaerobic decomposition of rice straw under waterlogged conditions, as compared with the aerobic decomposition. In one set of experiments, he demonstrated that apparently decomposition proceeded in two distinct phases. The first phase resulted in the rapid formation of organic acids, and the second phase transformed these acids into gaseous products. The latter process was more sensitive to pH and progressed at a maximum rate at about pH 7.5. The products of decomposition were acetic acid, butyric acid, CO_2, CH_4, and trace amounts of H_2. In the presence of neutralizing agents, over 20 liters of gas containing about 50 percent methane were obtained from the decomposition of 100 grams of straw. In subsequent studies on the composition of gaseous products, Acharya noted that the strictness of anaerobic conditions caused the amount of methane given off to increase, while CO_2 decreased and hydrogen first increased and then decreased. He also pointed out that maximum decomposition occurred at 30° C to 35 ° C at pH 8.0. Beyond this range, there was an accumulation of acids, and gas formation was suppressed.

Another essential feature of these studies was that the supply of available nitrogen was of paramount importance for aerobic decomposition, while it was relatively insignificant in anaerobic decomposition.

Yamane and Sato (1961) studied the decomposition of glucose, sucrose, starch, cellulose, gelatine, pectic acid, and lignin. Immediate evolution of hydrogen was observed where the soluble sugars were added. It was then followed by the formation of methane after the reabsorption of hydrogen by the soil. The hydrogen did not persist more than one day. In about two weeks large amounts of CO_2 and CH_4 were evolved from all but the lignin treatment. In the temperature range 15° to 60° C, the maximum production of gases was observed at 40° C. Below or above this temperature, the formation of gases was greatly suppressed.

From the foregoing studies, it can be safely concluded that organic acids rather than sugars constitute the basic substrate for the bacterial species that produce CH_4. The anaerobic carbon breakdown must, therefore, be characterized by the formation of organic acids, CH_4, and CO_2 as the major end products.

Regarding the decomposition of protein in a waterlogged soil, it may be said that the final end products are usually ammonia, carboxylic acids, amines, mercaptans, and hydrogen sulfide. The metabolic pathway of protein breakdown is probably the same under both waterlogged and well-drained soils until the formation of amino acids occurs. Under aerobic environments, the process of deamination takes place and the carboxylic acids thus formed are channelled into the Krebs cycle. The ammonia is either held on colloidal particles in exchangeable or non-exchangeable form or is oxidized to nitrate through the activities of nitrifiers. Under anaerobic conditions, on the other hand, the products of deamination and of subsequent decarboxylation may accumulate or be transformed into gaseous products.

B. Nitrogen Transformation in Soils

1. Forms and Distribution of Soil Nitrogen

A large proportion of soil nitrogen is represented by organically bound nitrogen and only a small amount appears in the inorganic fraction. It is this inorganic fraction, however, which is the immediate source of plant-available nitrogen. Organic nitrogen forms the potential reserve of nitrogen for the nutrition of plants but is available to plants only after it has been converted to the inorganic form.

a. Inorganic Nitrogen

The inorganic nitrogen in the soil constitutes only a small fraction of total soil nitrogen. It is present chiefly as ammonium and nitrate nitrogen. Nitrite may also be present as an intermediate product of nitrification, denitrification, and nitrate reduction. The amount present in normal soils, however, is generally negligible but may accumulate in neutral or alkaline soils, particularly when fertilized with high rates of ammonium (Martin *et al.*, 1943; Chapman and Liebig, 1952; Duisberg and Buehrer, 1954; Fuller, 1963). Accumulation of nitrite may also occur in acid soils which have been treated with anhydrous ammonia (Nommik and Nilsson, 1963) or with urea (Soulides and Clark, 1958; Clark *et al.*, 1960; Stephen and Waid, 1963). Hauck and Stephenson (1965) associated the nitrite accumulation with large granule size, low soil buffer capacity, an alkaline pH of the immediate granule environment, and heavy amounts of nitrogen application. The accumulation of nitrite in soil is probably due to the inhibiting effect of ammonium on the oxidation of nitrite to nitrate by Nitrobacter species (Broadbent *et al.*, 1957; Aleem and Alexander, 1960). Several other forms of inorganic nitrogen, such as hydroxylamine, hyponitrous acid, and nitramide, may occur as intermediates in the microbial processes leading to nitrification, nitrogen fixation, and denitrification. These compounds are chemically unstable, and hence are not detected during the course of analysis.

Most of the inorganic nitrogen present in the soil is water soluble or adsorbed on the exchange complex. Approximately 5 percent of the ammonium nitrogen in surface soils may be fixed in the lattice of silicate minerals in non-exchangeable form (Barshad, 1951; Allison *et al.*, 1953; Nommik, 1957; Stojanovic and Broadbent, 1960). The magnitude of ammonium fixation may be 30 percent or more in certain subsoils. The inorganic nitrogen constitutes a very dynamic system and undergoes rapid changes in its form and amount. Incorporation into microbial cell substance, immobilization in humus, absorption by plant, loss by volatilization, and absorption reactions in the crystal lattice are rather fast processes. On the other hand, inorganic nitrogen is continuously formed by the mineralization of the organic fraction. These fluctuations suggest that the amount of inorganic nitrogen determined at any one time may not represent the capacity of the soil to supply the inorganic nitrogen over a period of time.

The inorganic nitrogen regime in waterlogged soils is essentially characterized by the accumulation of ammonia and the absence of nitrates. This occurs because the mineralization of organic nitrogen does not proceed beyond the ammonium stage in the absence of oxygen, since oxygen is necessary for microbial conversion of ammonia to nitrate. As will be pointed out later in this report, however, special conditions can exist under which nitrates can be formed in waterlogged soils. The nitrates present in the soil before waterlogging may be removed by leaching, denitrification, and plant uptake. It is possible that some of the nitrate could be reduced to ammonia, but the amount reduced is very insignificant (De and Sarkar, 1936; Broadbent and Stojanovic, 1952; Wijler and Delwiche, 1954).

The presence of nitrite in waterlogged soil has been indicated (Janssen and Metzgar, 1928), but the amounts reported are invariably low. The levels of nitrite in waterlogged soils, including those fertilized with nitrate, generally lie in the range 0 to 3 ppm (Janssen and Metzgar, 1928; Kapp, 1932; De and Sarkar, 1936; Reed and Sturgis, 1937).

Ammonium nitrogen, which constitutes almost completely the inorganic pool of nitrogen in waterlogged soils, undergoes the same reactions in waterlogged soils as in well-drained soils, with the exception of nitrification, which is usually severely restricted. It can be taken up by plants, immobilized into cell substances, absorbed on the clay crystal lattice, and volatilized into the air under alkaline conditions. The degree and rate of these reactions depend on the conditions bringing about the transformation.

b. Organic Nitrogen

The nature of nitrogen-containing organic compounds occurring in soil is not well understood. Analytical difficulties in fractionation and determination have greatly hindered research on the nature and abundance of organic nitrogen compounds in soils. Nevertheless, information concerning these compounds has been obtained which adds to our understanding of the nitrogen transformation within the organic pool and its availability to plants. The usefulness of fractionation techniques is further realized in studies of the distribution of organic nitrogen compounds in the soil profile (Stevenson, 1957; Sowden, 1958; Bremner, 1958).

The methods used for fractionation of organic nitrogen in soils have been based largely on studies involving identification and estimation of the nitrogen compounds released by treatment of soils with hot acids. These methods are essentially modification of Hausmann (1899) and Van Slyke (1911-1912, 1915) classic methods of protein analysis. Fractions isolated generally include hydrolyzed ammonium N, amino N, non-amino N, humin N, and unhydrolyzed N (Kojima, 1947; Bremner, 1949a; Rendig, 1951; Stevenson *et al.*, 1957; Cheng and Kurtz, 1963; Stewart *et al.*, 1963). Recently, however, more specific methods of characterizing organic nitrogen substances have been developed which permit both determination and istope-ratio analysis of total N, ammonium N, hexosamine N, serine + threonine N, hydroxy amino acid N, and amino acid N in soil hydrolyzate (Bremner, 1965c).

The subject of distribution of nitrogen compounds in soil has often been reviewed (Tyurin, 1937; Waksman, 1938; Kojima, 1947; Ensminger and Pearson, 1950; Bremner, 1951, 1952, 1956; Harmsen and van Schreven, 1955; Scheffer and Ulrich, 1960; Kononova, 1961; and Russell, 1961). A comprehensive review has recently been published by Bremner (1965d); therefore no detailed account of the subject will be included here. However, a summary of present information about the nature, amount, and distribution of various organic nitrogen compounds in soils is incorporated.

Current information on the amount of total organic nitrogen in soils indicates that well above 90 percent of the total nitrogen in most surface soils is organically bound. It is, however, different in certain subsoils where about 30 to 40 percent of total nitrogen may be present as fixed ammonium (Bremner, 1965d).

The hydrolysis studies by Kojima (1947), Bremner (1949a), Stevenson (1954, 1956), Sowden (1956), Young and Mortensen (1958), and Kenney and Bremner (1964) have shown that 20 to 40 percent of the total nitrogen in most surface soils is represented by bound amino acid fraction. The amount of amino acids decreases with the depth in the profile (Stevenson, 1957c; Bremner, 1958b, 1959) and is affected by the cropping system, fertilization, and cultivation (Rendig, 1951; Stevenson, 1956b; Young and Mortensen, 1958; Porter *et al.*, 1964; Kenney and Bremner, 1964). The composition of amino acids in the amino N fraction of acid hydrolyzate shows the presence of several amino acids of the aliphatic and aromatic groups, some sulfur-containing amino acids, and heterocyclic amino acids (Bremner, 1965d).

Present information indicates that a considerable portion (15-25 percent) of soil nitrogen is released as ammonium by acid hydrolysis of surface soils (Bremner, 1949a; Cheng and Kurtz, 1963; Stewart *et al.*, 1963; Kenney and Bremner, 1964). The amount of ammonium released by hydrolysis in 6 *N* HCl increases with time of hydrolysis (Bremner, 1949a). Speculation has been made as to the origin of this fraction. There is some evidence that at least part of it comes from hydrolysis of amides (Sowden, 1958), and perhaps some comes from the decomposition of hydroxy amino acids and amino sugars. It also seems likely that some is formed by the deamination of other amino compounds occurring in the soil (Bremner, 1949a; Bremner and Shaw, 1954).

About 5-10 percent of the soil nitrogen in most surface soils is represented by amino sugar nitrogen in the form of hexosamines (Bremner and Shaw, 1954; Stevenson, 1957; Singh and Singh, 1960; Bremner and Kenney, 1964; Cheng and Kurtz, 1963). In several soils the proportion of hexosamines increased with the depth of the profile, reaching a maximum in the B horizon (Stevenson, 1957; Cheng and Kurtz, 1963; and Stevenson and Braids, 1968). No free amino sugars have been detected. The amino sugar N in soil appears largely in the combined form of high molecular weight substances. The nature of these substances is still obscure. Bremner (1955) detected both glucosamines and galactosamines in acid hydrolyzate of humic acid preparations and showed that from 3 to 10 percent of the nitrogen in these preparations was hexosamine N. Stevenson (1960) and Waldron and Mortensen (1961) further confirmed the presence of hexosamines in hydrolyzate.

The evidence as to the occurrence and amount of purine and pyrimidine derivatives indicates that these bases do not account for more than 1 percent of the surface soil nitrogen (Adams *et al.*, 1954; Anderson, 1961). Several other forms of organic nitrogen in the soil nitrogen pool have been identified but the amounts detected are insignificant (Waksman, 1938). Ethanolamine, choline, histamine, trimethylamine, allantoin, cyanuric acid, urea, etc. are examples of such compounds (Bremner, 1965d). Also, it has been theorized that some of the organic nitrogen compounds exist in unidentified forms, probably as lignin-ammonia, quinone-ammonia, quinone-amino acid, or carbohydrate-amino acid condensation products. However, there is very little evidence to support these theories, and the chemical nature of about 50 percent of the soil nitrogen has still to be explored.

The current information concerning the distribution of various nitrogenous organic compounds in waterlogged soils is very meager. From the few studies available (De and Mukherjee, 1951; De, 1956; and IRRI Annual Report, 1965) it can be postulated that the distribution pattern in waterlogged soils is about the same as in normal well-drained soils. Notwithstanding this generalization, flooding does bring some interchanges within the various fractions of organic nitrogen (IRRI Annual Report, 1965).

2. Distribution of Added Nitrogen in Soils

Little is known at present about the distribution of added inorganic nitrogen among various fractions of soil nitrogen. Recently, however, the advent of isotopic tracing techniques using ^{15}N as a tracer to differentiate between the added and the soil nitrogen, and the subsequent development in the fractionation and determination procedures (Bremner, 1965c) have made these studies possible. The importance of these studies lies in understanding the fate and distribution of applied nitrogen into various fractions of the soil nitrogen pool and its subsequent availability to the plant.

In general, it has been found that a large proportion of added nitrogen in surface soils is converted into the amino acid fraction and a smaller portion goes to amino-sugar components (Bremner, 1955; Sowden and Ivarson, 1959; Stewart *et al.*, 1963; Cheng and Kurtz, 1963). Bremner's (1955) study concerned the composting of plant residues and fertilizer nitrogen in the absence of soil. He showed that a large fraction of fertilizer nitrogen immobilized during the biological decomposition of straw was in the form of bound amino acids and a smaller fraction was in the form of sugars. Similar results were reported by Sowden and Ivarson (1959) in a decomposition study of forest litter. Since these studies were made in the absence of soil, no definite extrapolation of these results could be made to the soil system. Stewart *et al.* (1963) studied the nitrogen transformations in soil incubated with straw and various nitrogen fertilizers. Most of the nitrogen immobilized during the incubation was recovered in the nondistillable acid-soluble nitrogen fraction, which in this study was analogous to amino acid fraction. Although this nondistillable fraction constituted only about 50 percent of the total organic N, ^{15}N studies showed that about three times as much nitrogen entered the amino acid fraction as went to the other organic fractions. Further, they pointed out an inverse relationship between inorganic N and amino acid N. Similar conclusions were drawn by Cheng and Kurtz (1963) on three lysimeter soils previously fertilized with ^{15}N-enriched nitrogen and cropped to corn for two consecutive years. About 65 percent of the added nitrogen was recovered as amino acid components and slightly over 10 percent was detected in amino sugars. These two fractions together with the hydrolyzed ammonium fraction contained over 90 percent of the added fertilizer nitrogen in the soil. Very small amounts, usually 5-10 percent, went into soluble and insoluble humin N fractions. The fixation of added ammonium was insignificant (0-1 ppm).

Again, the information on the distribution of added nitrogen into the soil organic pool of nitrogen under waterlogged conditions is scanty. The soil microbiology group at IRRI (1965) studied the fate of applied nitrogen in submerged soils in order to investigate the movement of inorganic nitrogen into the organic fractions of soil nitrogen and its subsequent release. The most important organic nitrogen fractions in terms of immobilization were the hydrolyzed ammonium fraction, amino acid fraction, and amino sugars. Nitrogen entering the exchangeable ammonium fraction following submergence was largely derived from hydrolyzed ammonium, amino acid, and amino sugar fractions. An important feature emerging from this study was the fact that a considerable portion of applied nitrogen was not accounted for in any of the fractions isolated. Losses of this nitrogen through nitrification and subsequent denitrification were speculated.

These results indicate that the added nitrogen undergoes more or less similar changes, in so far as its distribution into various organic fractions is concerned, under both waterlogged and well-drained conditions, except that some of the applied nitrogen in waterlogged soils is probably lost through denitrification.

3. Mineralization and Immobilization of Nitrogen

a. General Concept

Of the various changes nitrogen can undergo in soil, the mineralization-immobilization cycle is the continuous one, but the two individual steps often achieve opposite goals. The mineralization process results in the transformation of organic nitrogen to the inorganic form of ammonium N or ammonia. It is carried out by the activities of general purpose heterotrophs which utilize nitrogenous organic compounds as their energy source. The immobilization process, on the other hand, transforms the inorganic nitrogen (ammonium, nitrite, nitrate) into organic compounds. The inorganic nitrogen is assimilated by microorganisms and metabolized into nitrogenous constituents of their cells. In general, mineralization is always accompanied by immobilization; the two processes tend to counteract each other so far as the production of inorganic N is concerned (Jansson, 1963).

In characterizing the biological turnover of nitrogen in soils, Jansson (1958) introduced the term "continuous internal cycle," in which he postulated that the mineralization-immobilization cycle repeats itself again and again, leading towards exhaustion if no fresh organic matter is added from outside. But when starting with plant residues with a high C:N ratio, it is mainly the carbon which is liberated and lost as CO_2 into the atmosphere during the consecutive cycles through the turnover, while the nitrogen is retained in the organic form and passes through the cycle many times, until the C:N ratio has become sufficiently reduced to allow for an accumulation of inorganic nitrogen. It is at this stage that the term "net mineralization" of nitrogen can be applied. Since the reactions of mineralization and immobilization are simultaneous and opposite in direction, it is the net mineralization or net immobilization which controls the amount of available nitrogen. It is possible to have little or no net effect even though the simultaneous processes of mineralization and immobilization are going on vigorously. The resulting net effect usually depends on the ratio between the carbonaceous material (energy source) and the nitrogen in substances undergoing decomposition (Jansson, 1963). As a general rule of thumb, the substances rich in nitrogen favor net mineralization and those poor in nitrogen favor net immobilization.

A quantification of nitrogen immobilization-mineralization has been given by Alexander (1961) to describe the interaction between microbial demand and supply. In the process of decomposition, carbon is released as CO_2 and organic nitrogen as ammonium. A simultaneous synthesis of additional microbial cell constituents results in the assimilation of carbon and nitrogen from either the environment or the substrate, depending on the type of microflora involved. To estimate the nitrogen needed for microbial cell synthesis, Alexander (1961) has developed a formula based on data using the amount of carbon assimilated and the C:N ratio of the cells synthesized. It is estimated that 5-10 percent of the substrate carbon is assimilated by bacteria, 30-40 percent by fungi, 15-30 percent by actinomycetes, and only 2-5 percent by anaerobic bacteria. The carbon content of microbial protoplasm is fairly constant and typically stays around 45-50 percent of the dry weight, but the nitrogen percentage is a variant factor and depends on the environmental conditions of the system. As an approximation, however, C:N ratios of 5:1, 10:1, and 5:1 have been proposed for the cellular components of bacteria, fungi, and actinomycetes, respectively (Waksman, 1924, quoted by Alexander, 1961). By combining the corresponding figures for carbon assimilation and for the C:N ratios of various microflora, it can be calculated that for the decomposition of 100 units of substrate carbon, it is necessary to provide 1 to 2, 3 to 4, and 3 to 6 units of nitrogen for aerobic bacteria, fungi, and actinomycetes, respectively, while only 0.4 to 1.0 unit of nitrogen is needed by anaerobic bacteria for the same degree of decomposition. To further illustrate this approach, it may be noted that with plant material having roughly 50 percent carbon, for each 100 grams of organic matter undergoing decomposition, 0.2 to 0.5, 0.5 to 1.0, 1.5 to 2.0, and 1.5 to 3.0 grams of nitrogen are needed by anaerobic bacteria, aerobic bacteria, fungi, and actinomycetes, respectively. These theoretical deductions, based almost entirely on the considerations of microbial nutrition, clearly define the role of microbial type in determining the extent of nitrogen immobilization and the consequent rate of inorganic nitrogen release. From the preceding example it is evident that immobilization is greatest for actinomycetes and least for anaerobic bacteria.

The importance of C:N ratio in the realm of nitrogen immobilization-mineralization can be realized in two important respects. First, the C:N ratio reflects the immobilization-mineralization pattern of nitrogen. Wider ratios stimulate immobilization, while the narrower ratios favor mineralization. Second, the C:N ratio is important because during the decomposition of plant material, carbonaceous substances furnish the energy source of microbes and nitrogen is assimilated and metabolized as protein in the synthesis of cell substances. However, due to certain errors involved in the determination of the C:N ratio, the use of nitrogen percentage is sometimes preferred as an index of nitrogen immobilization (Bartholomew, 1965).

Other useful indices have been introduced to express the extent of immobilization or nitrogen deficit following the addition of wide C:N ratio plant material. Hutchinson and Richards (1921) and Rege (1927) used the term "nitrogen factor" to express the nitrogen needs of plant material undergoing decomposition. It was defined as the number of grams of additional nitrogen needed in the decomposition of 100 grams of original plant material. Another useful index, "nitrogen equivalent," suggested by Richards and Norman (1931), was defined as the number of grams of nitrogen immobilized per 100 grams of material fermented.

The foregoing paragraphs summarize some of the essential features of the nitrogen immobilization-mineralization process. No detailed discussion of the subject under well-drained conditions will be included since several comprehensive reviews on this aspect of nitrogen transformation have been published (Harmsen and van Schreven, 1955; Dubber, 1955; Winsor, 1958; Jansson, 1958, 1963; Bartholomew, 1965; Drouineau, 1965; Allison, 1966).

Recent developments in the understanding of the nitrogen immobilization-mineralization process in soil may be attributed to the rather general adoption of ^{15}N-tracer techniques. Tracer studies permit both identification and quantification of components of the inorganic and organic soil nitrogen systems. Among the numerous studies on the tracer investigation of various aspects of immobilization and mineralization in soil the following are typical: Hiltbold *et al.*, 1951; Bartholomew and Hiltbold, 1952; Kirkham and Bartholomew, 1954, 1955; Wallace and Smith, 1954; Jansson, 1955, 1956, 1958, 1963; Stojanovic and Broadbent, 1956; Walunjkar *et al.*, 1959; Broadbent and Tyler, 1962; Broadbent, 1956, 1965; Stewart *et al.*, 1963; Overrein and Broadbent, 1964; Rothamsted Experiment Station Annual Report, 1965; and Van Den Hende, 1966. Excellent reviews on these studies have recently been published by Jansson (1958) and Allison (1966).

In contrast to the information available for nonflooded soils, the information on the nitrogen immobilization-mineralization process in waterlogged soils is meager and scattered. Recent reviews by Bartholomew (1965) and Patrick and Mahapatra (1968) reflect the lack of information. It is therefore intended to review the subject of nitrogen mineralization-immobilization in waterlogged soils as extensively as the limited data available will permit. A brief reference to normal well-drained soils will be made wherever necessary for comparison purposes.

b. Nitrogen Mineralization in Waterlogged Soils

The special condition prevailing in waterlogged soils leads to a considerable modification of the ammonification process and complete suppression of nitrification in soil zones which are devoid of oxygen.

The breakdown of organic matter which leads to the liberation of ammonium ions into the solution phase proceeds at a much slower rate in anaerobic environments than in an aerobic environment (Tenny and Waksman, 1930; Acharya, 1935a, 1935b, 1935c). This is because, as explained above, the degradation of organic matter in well-drained soils is caused by general purpose heterotrophic bacteria, fungi, and actinomycetes, of which the fungi are perhaps the most active. In waterlogging, a less efficient and more restricted bacterial microflora that does not require oxygen for respiration takes over the activities of the efficient fungal microflora. Hence, both mineralization and immobilization rates are considerably retarded. The characteristic features of anaerobic bacterial degradation of organic matter in waterlogged soils, therefore, comprise (1) incomplete decomposition of carbohydrate into methane, organic acids, hydrogen, and carbon dioxide with consequent low energy yield (Alexander, 1961); (2) low energy of fermentation, resulting in the synthesis of fewer microbial cells per unit of organic carbon degraded; for example, only 2 to 5 percent of the substrate carbon is assimilated by anaerobic bacteria compared with about 30 to 40 percent assimilation by fungi in aerobic system (Alexander, 1961); (3) low nitrogen requirement of the anaerobic metabolism leading to a more rapid release of ammonium ions than would ordinarily be expected because of the wide C:N ratio of decomposing plant material and the much slower rate of anaerobic decomposition. This explains why ammonium release is higher under anaerobic conditions than under aerobic conditions during the decomposition of a plant material with wide C:N ratio, despite its rapid decomposition under the latter condition. Practical illustration of this effect was perhaps first given by Acharya (1935c). In a laboratory study on the decomposition of rice straw under aerobic, partially aerobic (waterlogged), and strictly anaerobic conditions, he demonstrated that the rate of decomposition of straw, the nitrogen factor (number of grams of additional nitrogen required to decompose 100 grams of material), and the nitrogen equivalent (number of grams of nitrogen immobilized during the decomposition of 100 grams of material) were highest under aerobic conditions and lowest under anaerobic conditions. Conversely, the net release of inorganic nitrogen to the solution phase was highest in anaerobic and least in aerobic systems. Quantitatively, the nitrogen released to the aqueous extract by rice straw decomposing under anaerobic conditions was about 5 to 6 times higher than that released under aerobic conditions. The waterlogged treatment stood in between these two extremes. Sircar *et al.* (1940) presented similar evidence and reported that inorganic nitrogen release from decomposing rice straw occurred at a higher C:N ratio under anaerobic conditions. Further, they noted that a minimum nitrogen concentration of 1.7 to 1.9 percent was necessary for the aerobic release of nitrogen from decomposing rice straw, whereas only 0.45 to 0.50 percent was sufficient under anaerobic conditions.

From a field study in California on the decomposition of rice straw under flooded condition, Williams and co-workers (1968) concluded that the nitrogen requirements for the decomposition of rice straw in flooded soils was one-third (0.54 vs 1.5 percent) the average concentration of nitrogen required for aerobic decomposition of plant residues. From laboratory and field experiments Joachim and Kandiah (1929) concluded that the incorporation of green manure in puddled state leads to the formation of large quantities of ammonium.

Mitsui (1954) showed the marked influence of C:N ratio on the rate of inorganic nitrogen release. The accumulation of inorganic nitrogen followed the general order of C:N ratio under both flooded and non-flooded conditions. The soybean cake meal with narrowest C:N ratio (5.3:1) accumulated the largest amounts of inorganic nitrogen, whereas the peak value for materials with wider C:N ratio was delayed progressively as C:N ratio increased. Further, at wider C:N ratio (16:1) there was a relatively more rapid release of inorganic N under flooded than under non-flooded conditions, particularly during the first three months of incubation. Mitsui attributed this to the fact that anaerobic microbes predominate under waterlogged conditions and these microbes consume less nitrogen as microbical cell constituent than the aerobic microbes.

De Geus (1954) attributed the response of rice to added organic matter to the ready release of ammonium from anaerobic decomposition. Bhuyiyan (1949), and Lopez and Galvez (1958) reported that flooding increased the quantity of ammonium in soil solution to a maximum level, after which no appreciable change occurred.

Patrick and Wyatt (1964) found a considerably higher rate of inorganic nitrogen release in waterlogged soils than in well-drained soils. In a number of soils Waring and Bremner (1964) observed a more rapid rate of net mineralization under waterlogged than under aerobic conditions. Quantitatively, they showed that in a two-week period, for every

1 ppm of inorganic N produced aerobically, 1.23 ppm of ammonium N were produced during incubation under waterlogged conditions.

Another feature of anaerobic mineralization is its sensitivity to pH. This is expected, because the mineralization in waterlogged soils is essentially the work of anaerobic bacterial flora which operates most efficiently around or above neutral reaction. This may explain why the liming of paddy soils in Japan has sometimes been claimed to cause an appreciable increase in ammonification (Mitsui, 1954).

An additional feature of nitrogen mineralization under waterlogged soils has recently been discovered by Japanese investigation of the mechanism of mineralization of native organic nitrogen in paddy soils. Subjecting the waterlogged soil to various pretreatments produced a remarkable effect on the mineralization of native organic nitrogen. Among the various treatments studied, the following have been reported as the main factors influencing mineralization: (a) air drying the soil between the successive rice crops; (b) elevating the soil temperature in a flooded soil; (c) raising the soil reaction to pH 9.0 by addition of weak alkaline solution, and (d) adding a salt which may peptise the soil humus (Mitsui, 1954; Harada, 1959; Harada and Hayashi, 1968).

4. Losses of Nitrogen in Waterlogged Soils Through Denitrification

The phenomenon of denitrification under waterlogged conditions is so well studied that any review of the subject can hardly avoid needless repetition. This review will, therefore, discuss only those aspects of denitrification which are related to the special conditions prevailing in rice soils under which ammonium fertilizer applied to surface oxidized layer is first nitrified, moves down into the underlying reduced layer, and is then subsequently reduced through denitrification to N_2 or N_20. For better understanding of this reaction it is essential to consider the profile description of a typical paddy soil.

The profile differentiation in a waterlogged paddy soil is characterized by two distinct layers: (1) a surface oxidized layer, generally to a depth of a few millimeters to a centimeter or so, present at the soil-water interface, and (2) an underlying reduced layer (Pearsall and Mortimer, 1939; Pearsall, 1950; Mitsui, 1954; Alberda, 1953). The surface layer corresponds to an oxidized zone where microorganisms live aerobically. Below this zone is the reduced layer constituting the main part of the furrow slice where microorganisms live anaerobically. In the rhizosphere of rice roots, however, the conditions are altered again and the soil zone in close proximity to the rice roots is distinctly oxidized and, therefore, constitutes a condition similar to the surface oxidized layer (Mitsui, 1954).

The importance of this profile differentiation in the studies of nitrogen transformation in waterlogged soils was perhaps first realized in Japan. Shioiri and Mitsui (1935) observed considerable losses of nitrogen from applied ammonium sulfate as the period of incubation proceeded. The losses were apparently too great to be accounted for by direct volatilization or by other possible ways of nitrogen loss known at that time. Further experimentation to determine the effect of stirring on ammonia accumulation under waterlogged conditions led Mitsui to believe that, even under waterlogged conditions, ammonium may be nitrified to nitrate if it is applied to the flooded soil surface. Nitrate thus formed moves down into the anaerobic zone by percolation or by diffusion, and is subsequently denitrified biologically and possibly chemically to gaseous nitrogen. This process was subsequently confirmed by Pearsall (1950), Shioiri and Tanada (1954), and Mitsui (1954).

Studies conducted in various parts of the world indicate that these losses of nitrogen through nitrification and subsequent denitrification largely account for the low recovery of ammoniacal fertilizers by rice in waterlogged soils (IAEA, 1966). Abichandani and Patnaik (1955) estimated these losses to be 20 to 40 percent in India, while losses of 30 to 50 percent of applied nitrogen were reported from Japan (Mitsui, 1954). Other reports indicate the utilization of ammonium sulfate as low as 40 percent (Basak *et al.*, 1957; De and Digar, 1955; and Yamane, 1957). According to Amer (1960), the recovery of applied ammonium sulfate decreased with increased fertilizer levels. Nelson and Hauck (1965) indicated that even under the best conditions losses of about 10 to 20 percent are unavoidable.

Shioiri and Mitsui (1935) observed considerable losses of nitrogen in their mineralization study of organic matter under flooded conditions. The losses were more severe in case of soybean cake meal (C:N 5.3:1) than Spirogyra (C:N 20.1:1). Mitsui and Ota (1950), in a tracer study of nitrogen transformation, observed more losses of applied ammonium when the latter was applied to air-dried soil and then flooded than when the application was made directly to undried soil. Takijima (1959) reported the losses of nitrogen during incubation under flooded conditions in the following order of magnitude: urea, nitrate, ammonium. The cause of loss of nitrogen from urea was presumably volatilization by alkaline reaction of the soil, while the nitrate and ammonium were lost mainly through denitrification. Some of the nitrogen lost from urea was probably lost through denitrification after first being converted to ammonium and then to nitrate.

Subbiah and Bajoj (1962), while developing a soil test procedure for available nitrogen in waterlogged soils, indicated the possibility of nitrogen loss through nitrification and subsequent denitrification after about two weeks of incubation. Greenland (1962) reported that nitrification and denitrification could proceed simultaneously in a wet soil, possibly due to the presence of aerobic and anaerobic microzones. Patnaik (1965), in a tracer study of nitrogen transformation in waterlogged soils, could not account for 23-24 percent of the applied nitrogen at the end of incubation. He attributed this loss of nitrogen to the oxidation of ammonium to nitrate in the surface layer of soil with subsequent leaching and denitrification in the reduced subsurface zone. Tracer investigation (IRRI Annual Report, 1965) on the fate of ammonium sulfate under submerged conditions showed considerable losses of applied ammonium due to denitrification after about four weeks of incubation.

Deep placement of ammonium has invariably been shown to be superior to surface placement in various parts of the world (Abichandani, 1953; Shioiri and Tanada, 1954; Mitsui, 1954; Abichandani and Patnaik, 1955; Mikkelsen and Finfrock, 1957; Patrick and Miears, 1960; Patrick *et al.,* 1967; Yanagisawa and Takahashi, 1964; IAEA, 1966; Broeshart and Middelboe, 1968; De Datta *et al.*, 1968). Low recoveries of nitrogen under surface placement compared with deep placement are generally believed to be caused primarily by the biological oxidation of ammonium in the surface oxidized layer with subsequent leaching and denitrification in the reduced subsurface zone, although other factors such as volatilization and fixation by clay minerals may also contribute under certain soil conditions. High concentration of ammonia in conjunction with high pH, high temperature, and low cation exchange capacity would be ideal conditions for ammonia volatilization (Willis and Sturgis, 1944), while the presence of montmorillonite and illite leads to chemical fixation of ammonium into non-exchangeable form (Allison and Roller, 1955; Stevenson and Dhariwal, 1959; De Datta *et al.*, 1968).

Alternate wetting and drying conditions create an ideal environment for denitrification. Nitrate formed during the dry period is rapidly lost through denitrification when the soil is reflooded. Russell and Richards (1917) were perhaps the first to recognize the importance of alternate aerobic and anaerobic conditions on the loss of nitrogen. They observed that losses of nitrogen from farmyard manure occurred only under fluctuating aerobic and anaerobic conditions; no loss occurred when the material was maintained either under constant aerobic or under constant anaerobic conditions. They postulated that nitrate formed during aerobic conditions was subsequently denitrified at the onset of anaerobic conditions.

Wijler and Delwiche (1954) indicated the possibility of more total nitrogen loss under fluctuating aerobic and anaerobic conditions than under strict anaerobic conditions. Greenland (1962) pointed out that nitrification and denitrification could proceed simultaneously, possibly due to a micromosaic of aerobic and anaerobic spots in a wet soil. Russell (1961) attributed the nitrogen loss to the large fluctuations in the oxygen status of some soils in which nitrate is formed during the aerobic period and reduced during the anaerobic period.

Patrick and Wyatt (1964) observed large losses of nitrogen, up to about 20 percent of total N or 400 pounds per acre, as a result of several drying and submergence cycles. They noted that a major portion of this loss occurred during the first two or three cycles. Frequency of submergence and drying affected the total nitrogen loss and the rate of nitrate reduction in subsequent cycles. The disappearance of nitrogen was very rapid during the first submergence period but decreased subsequently as the number of cycles progressed. Further, they observed that the addition of ground rice straw to the soil increased the rate of nitrate reduction, even though the soil had already been through several submergence and drying cycles.

MATERIALS AND METHODS

A. Soils

The soil used for this study was Crowley silt loam, collected at two different times from the Rice Experiment Station, Crowley, Louisiana.

The Crowley silt loam No. 1 used in the first experiment was sampled in early spring 1967, air dried and sieved through a 40-mesh sieve. The soil had a carbon content of 1.02 per cent and a total nitrogen content of 770 ppm, with 6.0 ppm in the ammonium + nitrate form. The C:N ratio was 13:1. The soil had a pH of 5.8 in 1:1 soil-water suspension.

The Crowley silt loam No. 2 used in the tracer experiments was collected in February 1968. The soil had a pH of 5.7 (1:1 soil-water suspension), 1.10 percent carbon, and 840 ppm total nitrogen, of which 15.0 ppm was in the ammonium + nitrate form. The C:N ratio was 13:1.

B. Plant Material

1. Finely ground rice straw was used in this study. The material had 48 percent carbon and 0.52 percent nitrogen and the resulting C:N ratio was 92:1.

2. White clover hay was ground to a fine form and used in this study alone or in combination with rice straw to give various C:N ratios. The material contained 45 percent carbon and 3.07 percent nitrogen, giving a C:N ratio of 15:1.

C. Nitrogen Source

In all experiments dealing with tracer study, ^{15}N-tagged nitrogen was introduced into the soil system in the form of $(^{15}NH_4)_2SO_4$. The material contained 10.2276 atom-percent ^{15}N excess.

D. Description of Experiments

1. Mineralization of Organic Nitrogen in Soil from Plant Material of Various C:N Ratios Decomposing under Waterlogged and Optimum Moisture Conditions

This experiment was designed (1) to study the effect of waterlogging on the mineralization of organic soil nitrogen when incubated alone or mixed with ground straw which had been adjusted to several C:N ratios, and (2) to determine the effect of various C:N ratios on nitrogen mineralization under waterlogged and optimum moisture conditions. Crowley silt loam No. 1 was used in this experiment. A combination mixture of ground rice straw and ground clover was used to give desired C:N ratio values of the added organic material. The two materials were thoroughly mixed in such a proportion as to obtain the following C:N ratios: 92:1 (100% rice straw); 35:1 (66% rice straw + 34% clover straw); 21:1 (34% rice straw + 66% clover straw); 15:1 (100% clover straw).

Incubation Procedure:

One gram of ground mixed straw representing each of the four C:N ratios was thoroughly mixed with a 100-gram soil sample. The amended soil was then transferred to 12-ounce, previously tared medicine bottles. An additional treatment of unamended soil was included to serve as a check. A nitrification inhibitor, 2-Chloro-6-(trichloromethyl) pyridine (N-Serve), was used at the rate of 20 ppm in all the treatments to prevent nitrification of ammonium and to facilitate the determination of inorganic nitrogen as ammonium N. Each treatment was adjusted to either optimum moisture (25 percent moisture) or waterlogged (1:1 soil: water ratio). The samples were incubated in controlled temperature chambers into which saturated air was circulated to prevent drying of the samples. To ensure against moisture loss, the samples were frequently weighed and adjusted to the appropriate moisture content. At time intervals of 7, 14, 22, 30, 45, 60, 75, 105, and 135 days after incubation, duplicate samples of each treatment were removed for the determination of inorganic nitrogen.

2. Tracer Studies on Nitrogen Transformations in Soil with Special Reference to Immobilization, Mineralization, and Denitrification Relationships

This experiment was designed to examine in some detail the transformations of native and applied nitrogen under waterlogged and optimum moisture conditions. The objectives were to determine (1) the net and absolute rates of nitrogen immobilization and mineralization at various levels of added carbon under the two moisture conditions, (2) remineralization of immobilized labelled nitrogen, and (3) the extent of nitrogen loss under waterlogged conditions through a possible mechanism of nitrification of ammonium and subsequent denitrification. Crowley silt loam No. 2 was used in this investigation, with the following treatments:

(a) Untreated soil (control)
(b) Addition of 100 ppm labelled ammonium N
(c) Addition of 100 ppm labelled ammonium N + 1000 ppm carbon
(d) Addition of 100 ppm labelled ammonium N + 2500 ppm carbon
(e) Addition of 100 ppm labelled ammonium N + 4000 ppm carbon

Incubation Procedure:

Thirty-six samples representing each treatment were prepared by thoroughly mixing 100 grams of air-dry soil each with 0, 1000, 2500, and 4000 ppm of carbon in the form of ground rice straw. The samples were then transferred to 12-ounce bottles. Labelled ammonium sulfate solution equivalent to 100 ppm nitrogen, soil basis, was added in sufficient water (25 ml) to bring each sample to optimum moisture (25 percent moisture). This method of applying nitrogen corresponds to surface application of ammonium sulfate under field conditions. A control receiving no straw and no nitrogen was also included. Half of the samples were waterlogged by adding additional water (1:1 soil-water ratio) while the remaining half were maintained at optimum moisture (25 percent moisture). Samples thus prepared were incubated at 30° C with water-saturated air in the chamber to prevent drying. To ensure that the moisture content was maintained during incubation, the samples were frequently weighed and adjusted to the appropriate moisture content. At time intervals of 2, 4, 8, 15, 30, 45, 60, 90, and 120 days, duplicate samples of each treatment were removed for determination of ammonium + nitrate N and organic N and for ^{15}N isotope ratio analysis. No nitrification inhibitor was used in this experiment.

3. Tracer Studies on Nitrogen Transformations under Completely Anaerobic Soil Conditions

This study was designed to determine (1) the effect of a completely anaerobic condition on the fate of applied ammonium in the soil and (2) the effect of waterlogging *per se* on nitrogen transformations in soil.

This experiment was carried out as an extension of Experiment No. 2. Samples corresponding to treatment "d" (addition of 100 ppm labelled ammonium N + 2500 ppm carbon) were prepared and incubated at 30° C under the following conditions:

(a) Waterlogged anaerobic (air in bottle replaced with argon)
(b) Optimum moisture anaerobic (air in bottle replaced with argon)

Incubation Procedure:

One-hundred-gram soil samples were thoroughly mixed with ground rice straw equivalent to 2500 ppm carbon, soil basis, and transferred to 12-ounce bottles. Labelled ammonium sulfate equivalent to 100 ppm N, soil basis, was added in sufficient water to bring each sample to optimum moisture. The samples were then given the appropriate moisture and aeration treatment. The bottles were sealed with rubber serum caps and anaerobic conditions were induced by replacing air with argon by alternately applying a vacuum and oxygen-free argon to samples through a hypodermic needle. The gas renewal procedure was repeated weekly for several weeks after incubation. At time intervals of 2, 4, 8, 15, 30, 45, 60, 90, and 120 days after incubation, duplicate samples were taken for the determination of ammonium + nitrate N and organic N and for ^{15}N isotope ratio analysis.

4. Distribution of Applied Nitrogen into Different Chemical Fractions of Soil Nitrogen

This fractionation study of total soil nitrogen was made to determine the distribution of applied ammonium nitrogen into the various inorganic and organic fractions of soil nitrogen and to measure the changes within the various fractions of the native soil nitrogen pool under various conditions of moisture and aeration. This study was made on selected treatments of Experiments 2 and 3, when sampled at the end of a four-month incubation period. Untreated soil was included to serve as a reference of the initial distribution of soil nitrogen. The treatments were:

(a) Addition of 100 ppm ammonium N (waterlogged)

(b) Addition of 100 ppm ammonium N (optimum moisture)

(c) Addition of 100 ppm ammonium N + 2500 ppm carbon (waterlogged)

(d) Addition of 100 ppm ammonium N + 2500 ppm carbon (optimum moisture)

(e) Addition of 100 ppm ammonium N + 2500 ppm carbon (waterlogged anaerobic)

The fractionation and determination of nitrogen was carried out according to the methods described by Cheng and Kurtz (1963).

5. Nitrogen Loss as a Result of Alternate Submergence and Drying Conditions

This experiment was designed to measure the relative losses of applied and native nitrogen as a result of moisture fluctuations caused by alternately submerging the soil and then drying to optimum moisture for a total incubation period of four months. The effect of frequency of cycling on nitrogen loss was evaluated by varying the duration of the complete submergence and drying cycle but keeping the total incubation period constant. To study these effects, the following submergence and drying treatments were used:

(a) Alternate submergence and drying—30-day cycle (4 cycles)

(b) Alternate submergence and drying—40-day cycle (3 cycles)

Alternate submergence and drying—30-day cycle indicates that the samples were kept waterlogged during the first 15 days and were maintained at optimum moisture for the remaining 15 days. A 15-day period constituted a half cycle. Similarly, in the alternate submergence and drying—40-day cycle, a 20-day period constituted the half cycle.

Incubation Procedure:

Samples representing treatment "d" (Addition of 100 ppm ammonium N + 2500 ppm carbon) in Experiment 2 were prepared in accordance with the method outlined above. Appropriate treatments with respect to alternate submergence and drying were given, and the samples were incubated at 30° C. At the end of each submergence half cycle, samples were dried by blowing dry air over the samples at 30° C for 12 to 16 hours. The dried samples were then adjusted to optimum moisture (25 percent moisture). At the end of each half cycle duplicate samples were taken for the determination of ammonium + nitrate N, total N, and labelled N.

E. Analytical Procedures

1. Determination of Inorganic Nitrogen

a. Extraction

Inorganic nitrogen (ammonium + nitrate) was extracted from the soil by shaking 100-gram samples of either waterlogged or optimum moisture soil with 200 ml of 10 percent NaCl solution adjusted to pH 2.5. The samples were shaken for one hour and were then filtered, using a Buchner funnel. Distilled water was added to the optimum moisture samples immediately prior to shaking in order to give a moisture content equal to that of waterlogged samples.

b. Determination of Ammonium N

The ammonium N in the extract was determined by alkaline aeration of the extract. An aliquot of 150 ml of the extract was transferred to a 250-ml gas washing bottle, and then about 100 ml of saturated K_2CO_3 solution were added to the extract. The gas washing bottle was immediately connected to another gas washing bottle containing 100 ml of 2 percent boric acid solution. The washing bottle with the extract and the K_2CO_3 solution was then connected to a supply of ammonia-free air, which was bubbled through the solution for about 12 to 16 hours to sweep the ammonia into the boric acid solution. The ammonia was treated with standard 0.01 *N* HCl.

c. Determination of Total Inorganic N

The total inorganic nitrogen (ammonium + nitrate + nitrite) in the extract was determined by distillation with MgO and Devarda alloy added immediately before distillation (Bremner, 1965). The distillate was collected in standard 0.1 *N* H_2SO_4 and titrated with standard 0.1 *N* NaOH using methyl red indicator. The titrated solution was further prepared for ^{15}N analysis.

2. Determination of Organic Nitrogen

After the extraction of inorganic nitrogen the soil was oven-dried and analyzed for organic nitrogen by a modified Kjeldahl procedure. A soil sample equivalent to 5.00 gm, oven-dry basis, was placed in an 800-ml Kjeldahl digestion flask. About 10 ml of distilled water were added to the soil and allowed to stand for 20 minutes. The flask was then swirled carefully and 6 grams of digestion mixture (10 parts K_2SO_4, 1 part $FeSO_4$, ½ part $CuSO_4$) were added. Then 15 ml of concentrated H_2SO_4 were added and the contents were mixed by swirling the flask. The digestion was then commenced and continued for two hours after the solution had cleared. The digested material was allowed to cool, diluted to 200 ml with distilled water, and distilled after adding 50 ml of 50 percent NaOH. The ammonia released by distillation was collected in standard 0.1 *N* H_2SO_4 and determined by titration with standard 0.1 *N* NaOH. The titrated solution was further prepared for ^{15}N analysis.

3. Fractionation and Determination of Soil Organic Nitrogen

The procedure for fractionating soil organic nitrogen into its various components was that of Cheng and Kurtz (1963). Organic nitrogen was first divided into two categories: hydrolyzable nitrogen and non-hydrolyzable nitrogen. The former included hydrolyzed ammonium, amino sugars, amino acids, and acid soluble humin N, while the latter consisted of fixed ammonium and insoluble humin N.

a. Preparation of Hydrolyzate

Fifty-gram samples of soil previously extracted for exchangeable (ammonium + nitrate) N were washed with additional 200 ml of the extracting solution. The residue was then hydrolyzed with 6 *N* HCl under reflux for 16 hours at a soil/solution ratio of 1:4 at a temperature of 100° C. Boiling chips and octyl alcohol were added to prevent bumping and frothing during hydrolysis. After filtering, the acid hydrolyzate and the residue were saved for further fractionation and determination of hydrolyzable and non-hydrolyzable fractions.

b. Fractionation and Determination of Nitrogen Components in the Hydrolyzable Fraction

The excess acid in the hydrolyzate was removed by repeated evaporations under continuous aeration at 40° C by ammonia-free dry air. An aliquot of the hydrolyzate was taken for fractionating of the various hydrolytic products. The nitrogen in the hydrolyzate was divided into two categories: the alkali-labile N and the alkali-stable N. The alkali-labile N designates those fractions in the hydrolyzate which release ammonia under alkaline conditions, such as the hydrolyzed ammonium and the amino sugar N. The alkali-stable N in the hydrolyzate is that which is stable under alkaline conditions, such as amino acid N and acid soluble humin N.

(i). Alkali-labile N Fractions

The hydrolyzed ammonium was removed by the alkaline aeration method described previously under ammonium determination. Small amounts of 10 *N* NaOH were added to make the solution alkaline as shown by pH indicator paper. The ammonia released was collected into 100 ml of 0.01 *N* H_2SO_4.

After the aeration process, the residue hydrolyzate was heated in a Kjeldahl distillation unit to release the remaining amino sugar N as NH_3.

(ii). Alkali-stable N Fractions

After removing the alkali-labile N the remaining hydrolyzate solution was filtered to isolate the precipitated product, formed during alkalinization, from the solution phase. The solution contained the nitrogen fraction which was soluble in both acid and alkali but stable under alkaline conditions, such as amino acid N. The precipitates contained the acid soluble but alkali insoluble humin N.

The solution from above was treated by the Kjeldahl digestion and distillation method of the organic nitrogen analysis, described earlier in the section on the determination of organic nitrogen, to release amino acid N as NH_3.

Acid soluble humin in the precipitates was determined exactly the same way as amino acid fraction in the solution.

c. Fractionation and Determination of Nitrogen Components in the Non-hydrolyzable Fraction

(i). Insoluble Humin N

The residue, left after filtration of hydrolyzed soil, was determined by Kjeldahl digestion and distillation procedure as described for organic nitrogen determination.

The titrated solutions in all these fractions were prepared for ^{15}N analysis.

4. ^{15}N Techniques

a. Sample Preparation

The titrated samples containing nitrogen in the form of ammonium sulfate, a suitable starting material for ^{15}N analysis (Rittenberg, 1948), were evaporated to a concentrated form so that about 3 ml of the final solution contained at least 1 mg N per ml. This concentration was adequate for ^{15}N analysis. The concentrated samples were transferred to glass vials and stored in the refrigerator until analyzed.

b. ^{15}N Analyses

The ^{15}N analyses were carried out using a CEC 21-130 mass spectrometer, at the National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama, according to the method of Rittenberg (1946) as described by Bremner (1965c).

(i). Conversion of Ammonium to Nitrogen Gas

The conversion of ammonium N to nitrogen gas for mass spectrometer analysis was accomplished by treatment of 1 ml of the sample with 2 ml of alkaline sodium hypobromite solution in the complete absence of air. The N_2 gas evolved as described by the following reaction:

$$2\,NH_3 + 3\,NaOBr = 3\,NaBr + 3\,H_2O + N_2$$

The conversion of ammonium to N_2 was performed in a modified Rittenberg Y-tube designed to fit the mass spectrometer through a modified gas inlet system as described by Bremner (1965c). The design of this conversion apparatus eliminated the problem of air leakage during conversion of ammonium to N_2 and minimized other difficulties in the subsequent analysis of this gas.

(ii). Determination of Isotopic Composition of Nitrogen

The N_2 produced under high vacuum during the reaction of alkaline sodium hypobromite with the sample was led to the gas inlet system of the mass spectrometer through a U-tube immersed in a liquid nitrogen trap. The gas was then introduced into the ionization chamber at a regulated pressure predetermined to give effective ionization of gas molecules.

(iii). Calculation of Results

The mass spectrometer measured the ratio of the intensities of the currents produced by two isotopic ion beams. In the case of nitrogen, the measured ratio (R) is that of the ion currents corresponding to mass 28 ($^{14}N^{14}N$) and mass 29 ($^{14}N^{15}N$), i.e.:

$$R = \frac{^{14}N^{14}N}{^{14}N^{15}N}$$

Isotopic abundances are expressed in terms of atom-percent of the isotope under investigation. To calculate atom-percent of ^{15}N the following relationship was used.

$$\text{Atom-percent } ^{15}N = \frac{100}{2R + 1}$$

Further calculations for atom-percent ^{15}N excess and labelled N recovered were made after Jansson (1958).

RESULTS AND DISCUSSION

A. Mineralization of Organic Nitrogen in Soil from Plant Material of Various C:N Ratios Decomposing under Waterlogged and Optimum Moisture Conditions

This experiment consisted of a comparative study of the rate of nitrogen mineralization in Crowley silt loam, under two moisture regimes with and without added straw of various carbon:nitrogen (C:N) ratios. The samples were incubated under waterlogged and optimum moisture (25 percent moisture) conditions. A nitrification inhibitor was added in an attempt to prevent nitrification of ammonium formed during the mineralization process. The results obtained are given in Figure 1.

The nitrogen mineralization rates, in terms of ammonium accumulation, followed the general order of C:N ratios under both waterlogged and optimum moisture conditions. Addition of ground clover corresponding to a C:N ratio of 15:1 caused the accumulation of the largest amounts of ammonium N. Peak values of ammonium accumulation for wider C:N ratios (21:1, 35:1, 92:1) were progressively lower as the ratio increased.

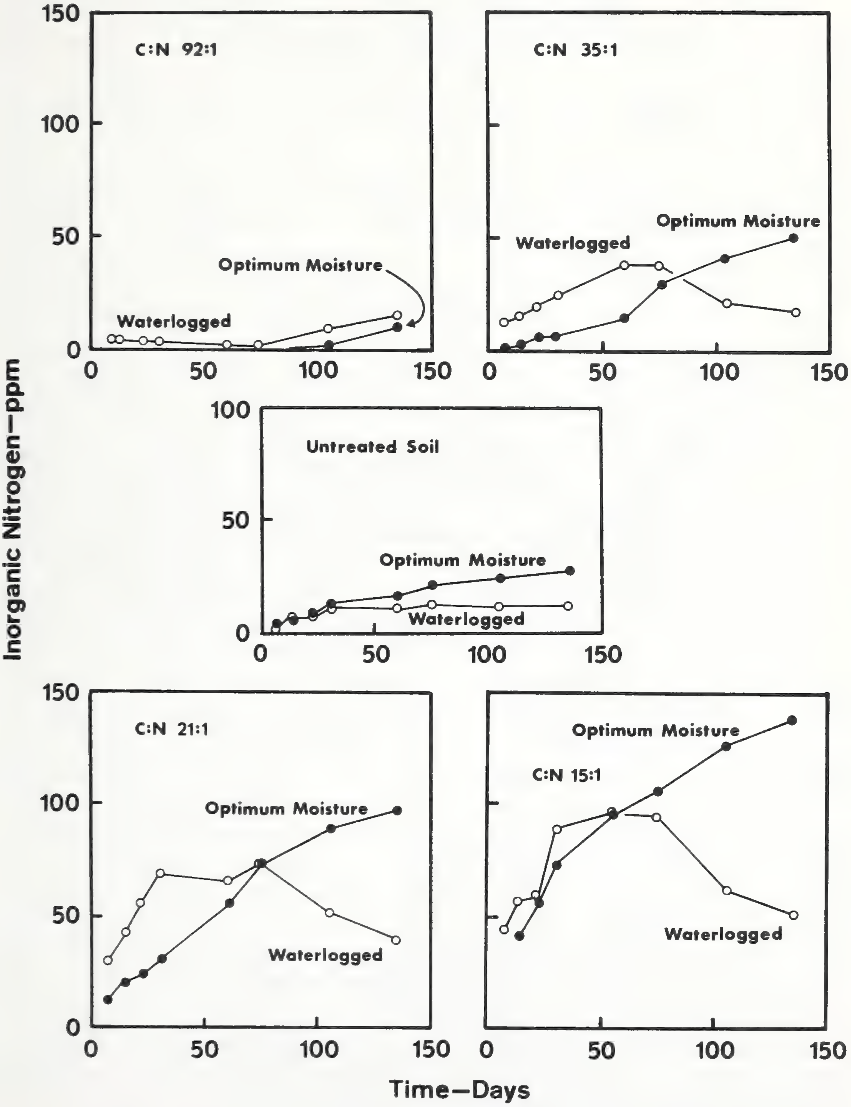

Figure 1.—Mineralization of organic nitrogen at various C:N ratios of added plant material under waterlogged and optimum moisture conditions.

Of special interest in this study were the comparative rates of ammonium accumulation under waterlogged and optimum moisture conditions over the wide range of C:N ratios. A close examination of Figure 1 reveals that during the first two months of incubation appreciably higher values of ammonification were recorded under waterlogged than under optimum moisture conditions. This is the pattern to be expected based on results of other investigators. After this initial period, however, the ammonium content of the waterlogged soil actually decreased so that by the end of the 150-day incubation period there was less ammonium in the waterlogged samples than in the optimum moisture samples.

About the same general pattern of ammonium accumulation was observed at various C:N ratios of the added plant material. At a wide C:N ratio (92:1) there was hardly any release of ammonium during early stages of incubation. However, a slight accumulation of ammonium was noted towards the end of incubation, with a higher amount being released under waterlogged than under optimum moisture conditions.

The results of this experiment point out two important features of nitrogen mineralization under waterlogged conditions in contrast with optimum moisture conditions: (1) a relatively higher accumulation of ammonium N during the first two months of incubation, and (2) a subsequent decline in ammonium accumulation at later stages of incubation. The initial rapid accumulation of ammonium under waterlogged compared with that at optimum moisture can be attributed to the low nitrogen requirements of anaerobic metabolism. Since anaerobic bacteria operate at a low fermentation energy, the synthesis rate of the new cell material is very low. Thus, the nitrogen immobilized during the anaerobic decomposition should be less, and that released to the soil solution should be high. On the contrary, aerobic metabolism results in a vigorous decomposition of organic matter coupled with a high incorporation of nitrogen. Thus, despite the rapid decomposition, the release of nitrogen is small until the substrate reaches a C:N ratio less than about 16:1 (Waksman, 1932). Acharya (1935c) and Sircar *et al.* (1940) presented similar evidence and reported that nitrogen released by rice straw decomposing under anaerobic conditions was about 4 to 6 times that released under aerobic conditions, although the decomposition rate was much higher under the latter conditions. Williams *et al.* (1968) likewise indicated that under field conditions the nitrogen requirement for the decomposition of rice straw in flooded rice soils was about one-third of the average concentration of nitrogen required for organic residue decomposition in a normal well-drained soil.

Some practical aspects of considerable agronomic importance may be anticipated from these results. Rice crop residues ordinarily requiring disposal prior to the planting of the next crop may be incorporated without causing appreciable nitrogen immobilization. It is possible that the decomposing straw, when produced under moderately high nitrogen conditions, will release nitrogen during the growth period of the rice crop. Williams *et al.* (1968) provided evidence substantiating these effects under field conditions.

As mentioned above, the second feature of nitrogen mineralization brought out in this study was the decline in ammonium content during latter stages of incubation. The exact nature of this nitrogen loss cannot be definitely ascertained. The loss probably arose as a result of ammonium formed during mineralization being nitrified in the upper oxidized zone and then moving into the lower anaerobic zone where it was denitrified. A nitrification inhibitor was added to the soil at the beginning of incubation, but it was probably not effective after two months. The possibility of nitrogen loss through denitrification was suggested by subsequent studies, which are discussed later in this report.

B. Tracer Studies on Nitrogen Transformations in Soil with Special Reference to Immobilization, Mineralization, and Denitrification

1. Immobilization-Mineralization Reactions

The amounts of inorganic and organic nitrogen present in the soil at various times after incubation in the second experiment are presented in Figures 2 to 5. Both labelled and unlabelled nitrogen are shown for each of these two fractions. These figures give an indication of the net immobilization or mineralization of nitrogen.

The results illustrated by Figure 2 show that under optimum moisture conditions a net mineralization of organic nitrogen was going on continuously in the untreated soil and accounted for about 32 ppm N during the four-month incubation period. Under waterlogged conditions the increase in inorganic nitrogen indicating net mineralization was manifested only during the first month of incubation. After this time the inorganic nitrogen decreased at a gradual rate even though the mineralization of organic nitrogen continued throughout the incubation period. The amount of organic nitrogen thus mineralized that did not quantitatively show up in the corresponding inorganic fraction indicated a loss of nitrogen from the system.

In the treatment where 100 ppm ammonium N was added to the untreated soil and maintained at optimum moisture conditions (Figure 3), there was rapid immobilization of applied ammonium during the first week of incubation. The net immobilization reached about 28 percent of the applied nitrogen by the eighth day. After this time a continuous and vigorous net mineralization occurred, resulting in an increase of about 50 ppm N in the total inorganic nitrogen pool. The amount of tagged nitrogen found in the inorganic state increased during the net mineralization period of the experiment, but at a much slower rate than the net mineralization. The changes in the corresponding gross and labelled organic nitrogen fractions further indicated that the initial rapid, but small, net immobilization was followed by a vigorous and

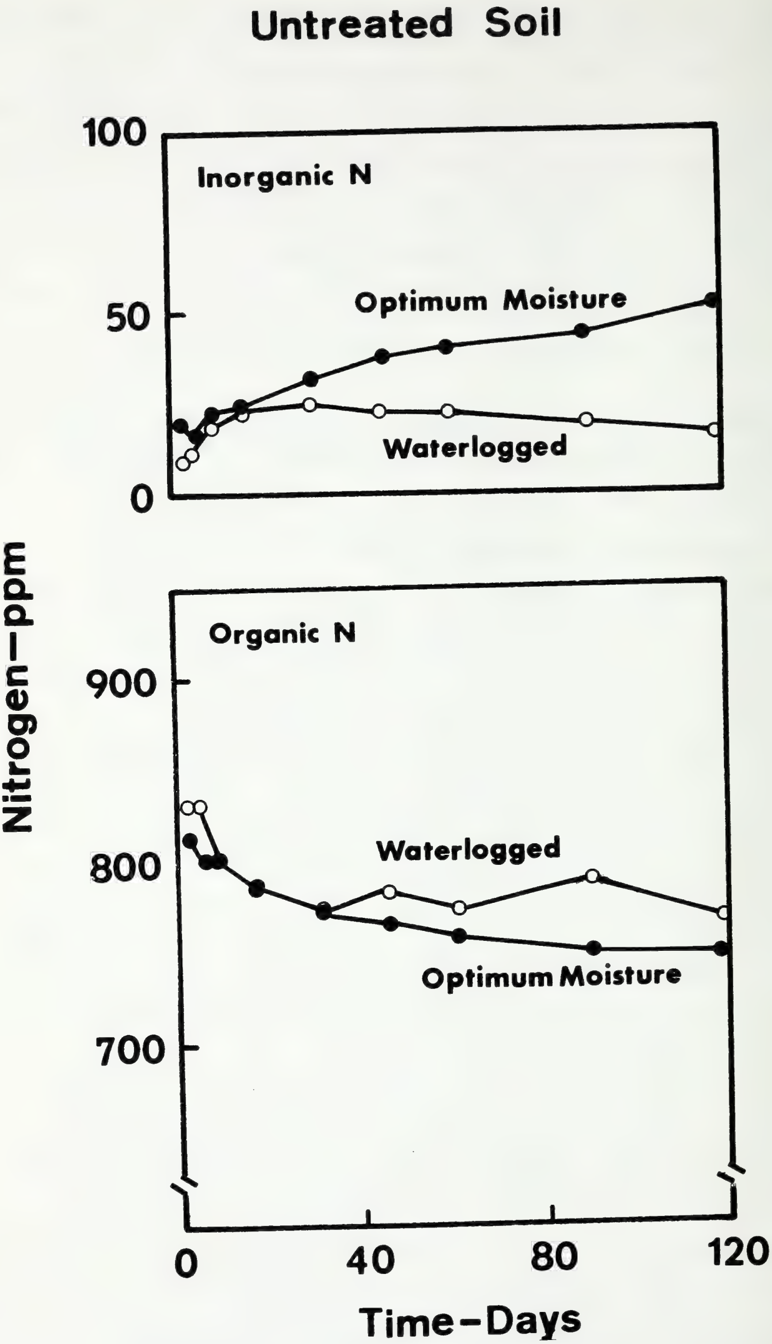

Figure 2.—Changes in inorganic and organic nitrogen under waterlogged and optimum moisture conditions in soil to which no additional nitrogen was added.

continuous net mineralization. It is interesting to note from these data that the addition of inorganic nitrogen caused a considerable nitrogen turnover even in the absence of added energy material.

Figure 3 also illustrates the immobilization-mineralization relationship under waterlogged conditions. The continuous decrease in total and labelled inorganic fractions apparently gave an indication of continuous net immobilization, but this was not really the case. The nitrogen leaving the inorganic fraction did not appear in the organic fraction, but was lost from the soil. Sixty-eight percent of the added labelled ammonium N could not be accounted for at the end of the experiment. The tracer data on the movement of inorganic nitrogen to the organic

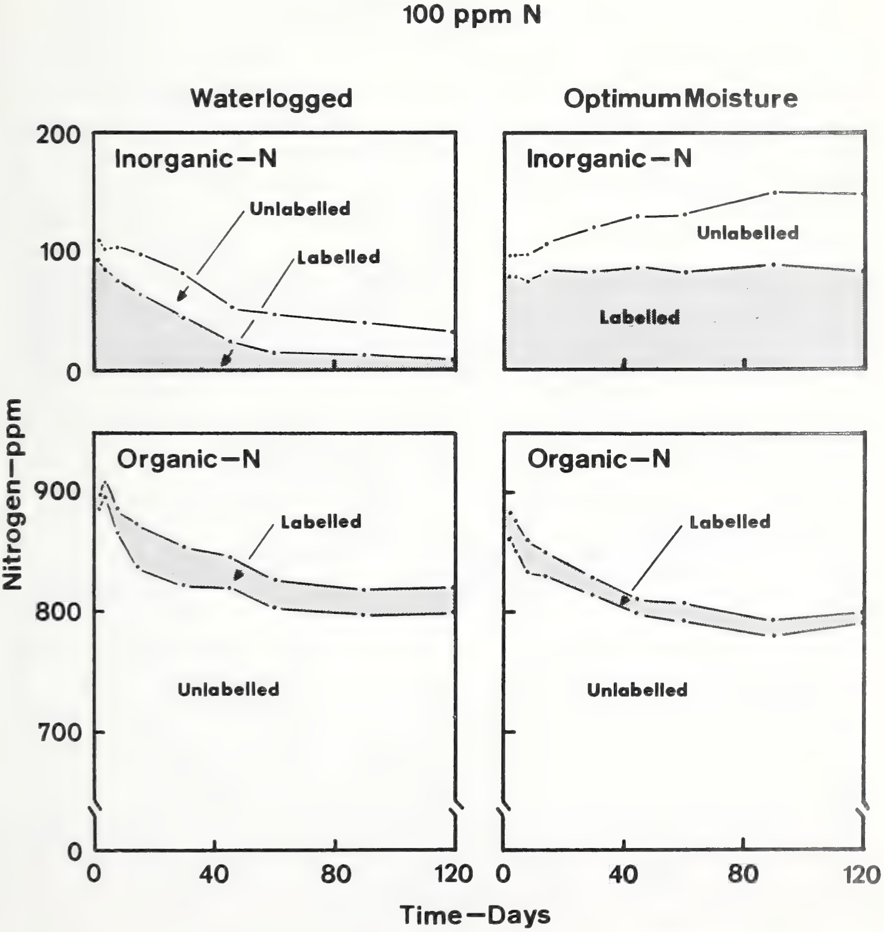

Figure 3.—Changes in the gross and labelled inorganic and organic nitrogen under waterlogged and optimum moisture conditions in soil receiving 100 ppm ammonium nitrogen.

phase showed that immobilization of applied nitrogen was completed by the fifteenth day of incubation. After this time no further net immobilization appeared, but rather a small remineralization of immobilized labelled nitrogen occurred.

Figure 4 depicts the immobilization-mineralization changes in the soil where rice straw (1000 ppm carbon) was added in addition to 100 ppm ammonium nitrogen. The straw increased considerably the net immobilization of inorganic nitrogen in the organic phase. A maximum in immobilization was observed by the eighth day of incubation. From this time on, a rather vigorous net mineralization occurred. Regarding the turnover of applied nitrogen, maximum immobilization amounting

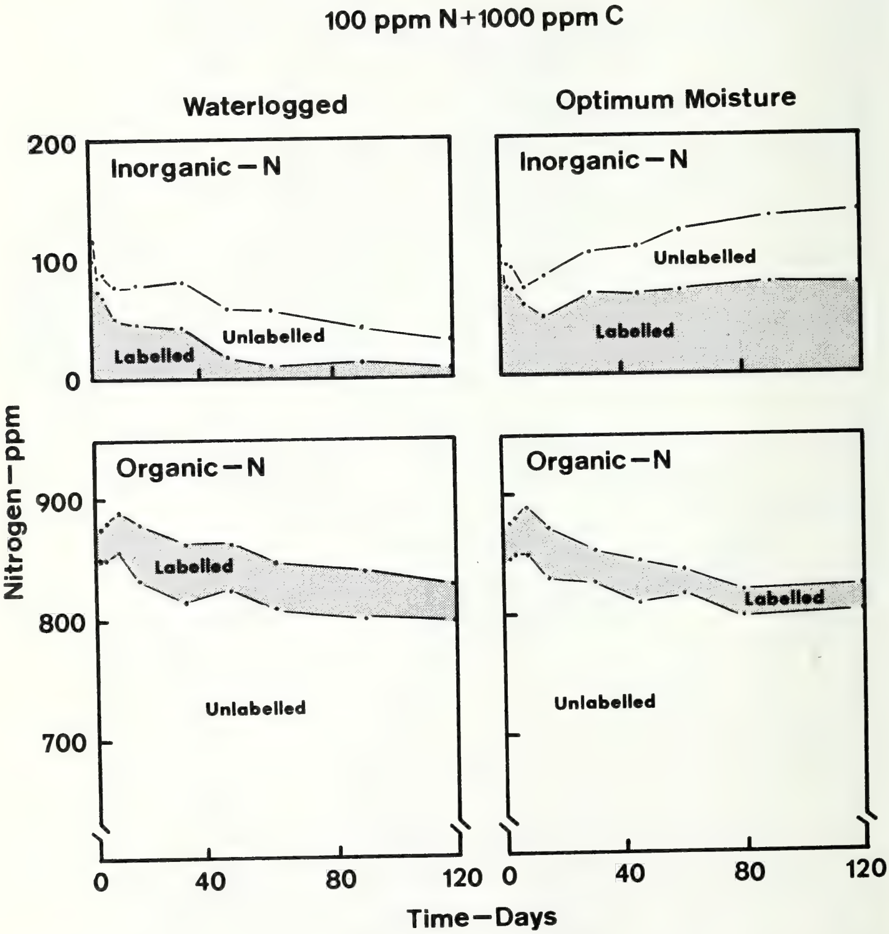

Figure 4.—Changes in the gross and labelled inorganic and organic nitrogen under waterlogged and optimum moisture conditions in soil receiving 100 ppm ammonium nitrogen and 1000 ppm carbon as rice straw.

to about 42 percent of the added nitrogen occurred during the first 15 days. This was then followed by rapid remineralization of the recently immobilized labelled nitrogen for the next 15 days. After this time remineralization proceeded at a very slow rate.

The changes in gross and labelled organic nitrogen fractions also indicate a similar immobilization-mineralization relationship as summarized above from the inorganic N data. The initial rapid increase followed by a subsequent vigorous decrease in the gross organic N fraction corresponds, respectively, to the initial net immobilization and subsequent net mineralization. A moderate change in the labelled organic nitrogen (shaded area) illustrates a relatively slow mineralization rate of the recently immobilized labelled nitrogen, particularly during the latter part of the incubation.

Under waterlogged conditions (Figure 4) a continuous decrease in the inorganic labelled nitrogen indicates that the nitrogen from the inorganic pool was being constantly removed, either by immobilization into the organic phase or through some other mechanism. Since this decrease in the inorganic fraction in waterlogged soil was not accounted for by an increase in the corresponding organic fraction except for the first eight days, it is evident that loss of nitrogen from the system occurred at a gradually decreasing rate during the last three and one-half months of incubation.

Conclusive evidence of nitrogen loss was suggested by considerably lower recoveries of labelled nitrogen towards the end of incubation. Only 42 percent of the applied nitrogen was accounted for, both in the inorganic and organic fractions of soil nitrogen, indicating a net loss of about 58 percent of the applied nitrogen. This loss was in addition to the nitrogen loss from native soil organic nitrogen that became mineralized during the incubation period.

Figure 5 indicates that straw addition at a rate of 2500 ppm carbon to soil treated with 100 ppm ammonium N caused a vigorous net immobilization of inorganic nitrogen in the soil maintained at optimum moisture. A minimum of 10 ppm in inorganic nitrogen was present on the thirtieth day of incubation. There was then a rapid increase in inorganic nitrogen, indicating that the initial net immobilization was changed into a rather vigorous net mineralization. The data for labelled inorganic nitrogen that moved into the organic phase likewise indicate that the maximum immobilization, amounting to about 87 percent of applied nitrogen, occurred during the first month of incubation. This was then followed by a rapid remineralization of the immobilized labelled nitrogen. Thus, immediately after maximum immobilization, the amounts of labelled nitrogen present in the inorganic fraction increased at a rather fast rate during the net mineralization period. These conclusions were further supplemented by the data on changes in gross and labelled organic nitrogen.

Under waterlogged conditions a continuous decrease in inorganic nitrogen occurred without any corresponding increase in the organic fraction, indicating that, except for the initial periods, processes other than immobilization accounted for the continuous removal of inorganic nitrogen. This complicated any evaluation of immobilization-mineralization relationship from the data on inorganic nitrogen. However, from the tracer nitrogen that moved into the organic fraction, it was calculated that a vigorous net immobilization equivalent to about 54 ppm N occurred under waterlogged conditions. Nevertheless, the high levels of immobilization encountered in the corresponding optimum moisture treatment were never reached. Little mineralization of the immobilized labelled nitrogen occurred.

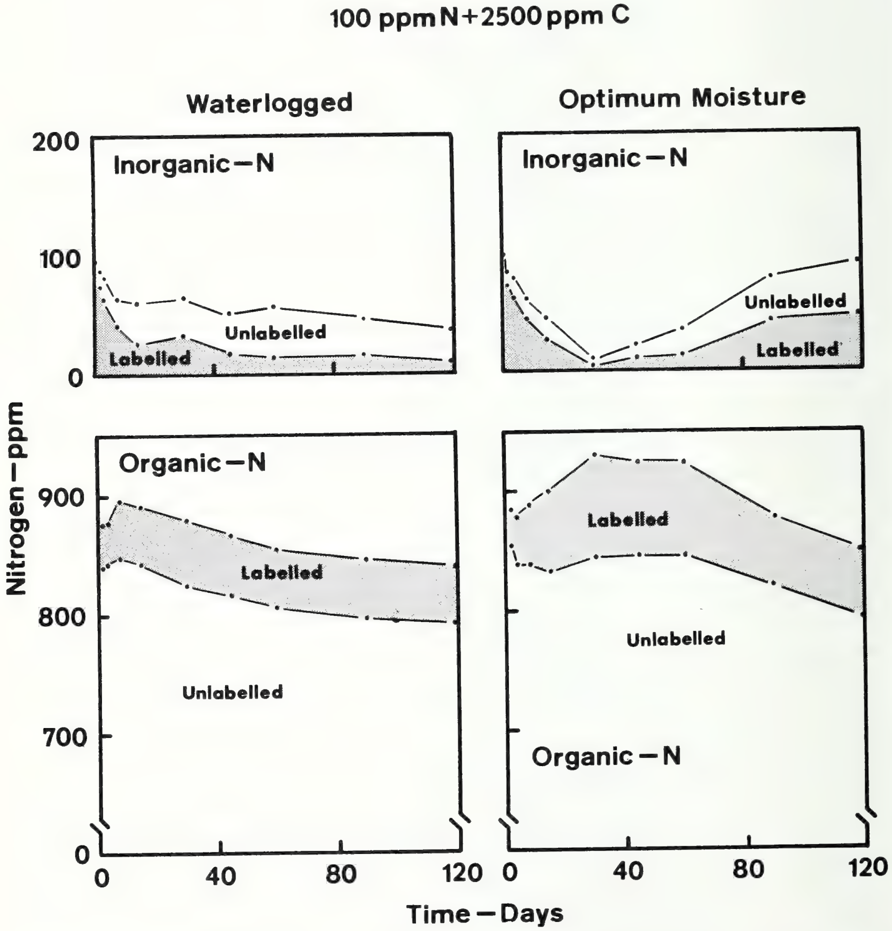

Figure 5.—Changes in the gross and labelled inorganic and organic nitrogen under waterlogged and optimum moisture conditions in soil receiving 100 ppm ammonium nitrogen and 2500 ppm carbon as rice straw.

The biological nitrogen turnover was also studied under completely anaerobic conditions (air replaced with argon). Figure 6 illustrates changes in inorganic and organic nitrogen under optimum moisture-anaerobic (optimum moisture, air replaced with argon) and waterlogged-anaerobic (waterlogged, air replaced with argon) conditions. The curves representing nitrogen change under the two anaerobic moisture regimes are so similar, both qualitatively and quantitatively, that hardly any difference between the two can be noticed. In other words, the results show that under anaerobic conditions waterlogging *per se* had no effect on the nitrogen transformations in soil. Regarding immobilization-mineralization reactions under anaerobic conditions, Figure 6 shows

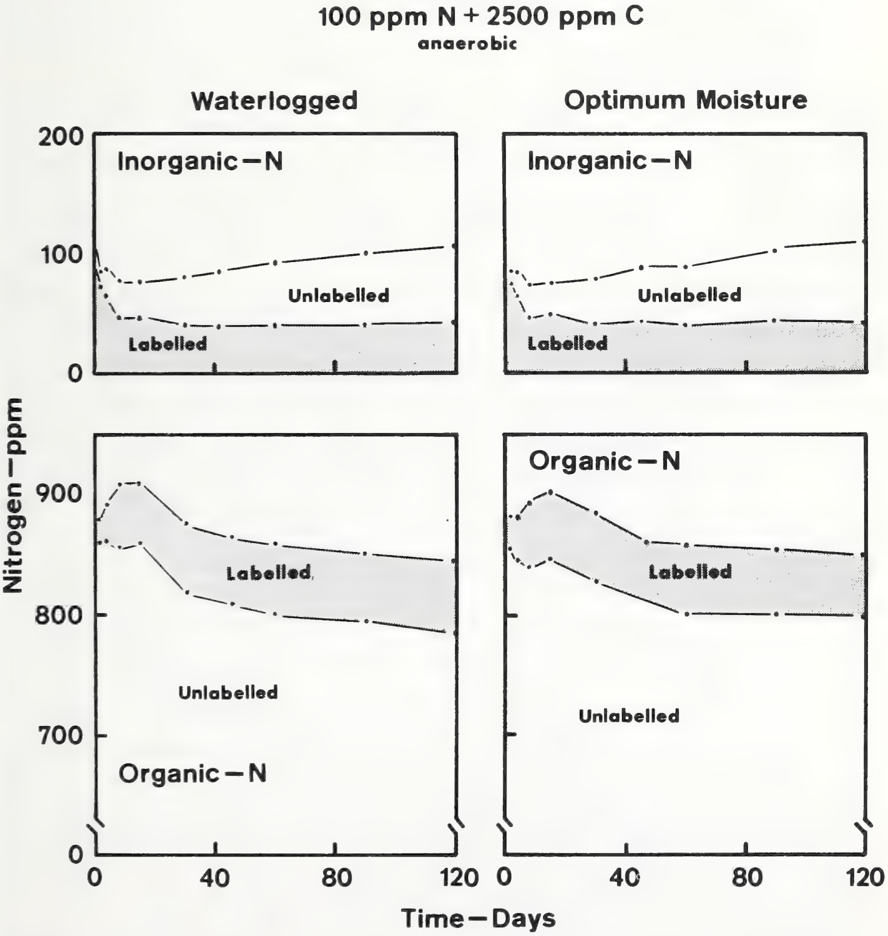

Figure 6.—Changes in the gross and labelled inorganic and organic nitrogen under waterlogged-anaerobic and optimum moisture-anaerobic conditions in soil receiving 100 ppm ammonium nitrogen and 2500 ppm carbon as rice straw.

that immobilization proceeded at a fairly rapid rate. However, the high immobilization values of its counterpart aerobic system (Figure 5, optimum moisture) were never reached, indicating that both the rate and magnitude of net immobilization were reduced by the anaerobic conditions. About eight days after incubation the net immobilization changed to net mineralization. From there on, the latter continued at a much faster rate. It is important to note that, unlike immobilization, the net mineralization proceeded at a higher rate under anaerobic than under aerobic conditions (Figures 5 and 6). This observation is in close accordance with the findings of Acharya (1935c) and Tenny and Waksman (1940). It is significant that the nitrogen mineralization took place at the expense of the native organic soil nitrogen and not from the recently immobilized labelled nitrogen. Tracer data for the labelled nitrogen in the inorganic phase reveal that after the maximum immobilization stage the amounts of labelled nitrogen in the inorganic state did not increase.

Another important feature of nitrogen transformation under anaerobic conditions is that there was no loss of nitrogen from the system as compared with a marked loss under comparable waterlogged treatment. The loss of nitrogen encountered under waterlogged conditions may be due to the partially aerobic nature of waterlogged systems in which the interfacial area is aerobic and leads to the biological oxidation of ammonium to nitrate. The nitrate in turn may diffuse into the underlying anaerobic zone and undergo denitrification. The details of this mechanism are discussed later in this report.

Figure 7 shows that when the addition of rice straw to soil treated with 100 ppm ammonium N was increased to about 4000 ppm carbon, a vigorous net immobilization occurred under optimum moisture conditions. The maximum in net immobilization was marked by the complete absence of nitrogen in the inorganic phase on the thirtieth day of incubation. There then followed a rapid increase in inorganic nitrogen, showing that initial net immobilization was changed into a rather vigorous net mineralization. The amount of labelled nitrogen found in the inorganic state also increased during the net mineralization period of the experiment at about the same rate as unlabelled inorganic nitrogen (Figure 7). Quantitatively, the net mineralization accounted for about 81 ppm of inorganic nitrogen, of which about 37 ppm was contributed by the recently immobilized labelled inorganic nitrogen. This immobilization-mineralization relationship is also depicted by the changes in gross and labelled organic nitrogen. The net immobilization of nitrogen is shown by an increase in gross organic fraction and, similarly, net mineralization is indicated by a decrease in the organic fraction. The decrease in labelled organic nitrogen (shaded area) denotes high remineralization rate of the immobilized labelled nitrogen.

Figure 7 also illustrates the interchange between inorganic and organic nitrogen under waterlogged conditions. The addition of 4000 ppm of carbon caused a much more vigorous net immobilization than was earlier observed at lower levels of straw addition. However, the high immobilization rate of a comparable optimum moisture treatment (Figure 7) was never reached. Tracer data, on the inorganic nitrogen that moved into the organic fraction, revealed that about 58 percent of the applied ammonium N was immobilized during the first 30 days of incubation. After this, little or no further net immobilization occurred, although a continuous removal of nitrogen from the inorganic phase was constantly noted. The latter may have been due to a net loss of nitrogen from the system, as was earlier noted for the waterlogged treatments. No direct evidence of net mineralization was noted from the inorganic phase; however, the continuous decrease in gross organic

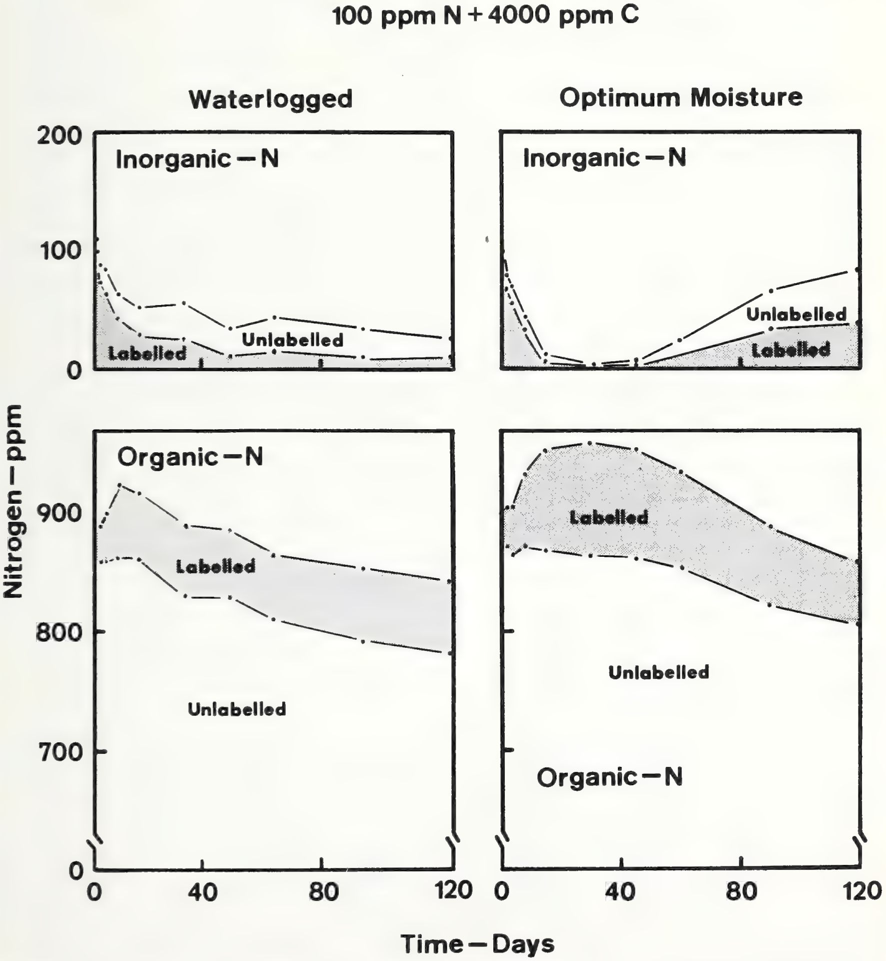

Figure 7.—Changes in the gross and labelled inorganic and organic nitrogen under waterlogged and optimum moisture conditions in soil receiving 100 ppm ammonium nitrogen and 4000 ppm carbon as rice straw.

nitrogen did indicate that, immediately after maximum immobilization, net mineralization dominated at a rather fast rate during the rest of the incubation period.

2. Remineralization of Immobilized Labelled Nitrogen

In the foregoing discussion of the nitrogen immobilization-mineralization relationship, reference was made to remineralization of immobilized labelled nitrogen. More discussion is needed on the rate and extent of remineralization under the various experimental conditions. A summary of the data showing maximum immobilization of applied nitrogen and the remineralization of immobilized labelled nitrogen is given in Table 1.

At the turning point, that is, at the stage when the initial net immobilization of inorganic nitrogen was changed into net mineralization, the remineralization of immobilized labelled nitrogen occurred at a rather rapid rate but slowed down considerably as the incubation period proceeded. Consequently, little or no remineralization occurred towards the end of the incubation period. Regarding the effect of moisture and aeration treatment, the remineralization rate was most rapid under optimum moisture and least pronounced under anaerobic conditions. The waterlogged treatment was intermediate between the two. It is important to note that in the case where 2500 ppm C as rice straw was added, unlike net mineralization, the rate of remineralization of immobilized labelled nitrogen was more rapid under optimum moisture

TABLE 1.—Remineralization of immobilized labelled nitrogen

Treament	Moisture	Labelled organic N		Net remineralization	Percent remineralization
		At maximum immobilization stage	At end of incubation		
		ppm - N			
100 ppm N	Optimum Moisture	25.6	11.9	13.7	53.5
	Waterlogged	35.1	20.4	14.7	41.9
100 ppm N + 1000 ppm C	Optimum Moisture	42.1	22.9	19.2	45.6
	Waterlogged	47.5	32.8	14.7	30.9
100 ppm N + 2500 ppm C	Optimum Moisture	86.9	54.3	32.6	37.5
	Waterlogged	53.6	46.4	7.2	13.4
	Anaerobic	58.1	57.1	1.0	1.7
100 ppm N + 4000 ppm C	Optimum Moisture	92.7	62.0	30.7	33.1
	Waterlogged	57.7	55.9	1.8	3.1

than under waterlogged or anaerobic conditions. It may be recalled that the reverse was true in the case of mineralization. The diffference in the rate and magnitude of remineralization under optimum moisture and waterlogged conditions widened as the ratio between added carbon and nitrogen increased. Tracer data on the movement of labelled nitrogen into and out of the organic fraction give a quantitative indication of remineralization of immobilized labelled nitrogen under various experimental conditions. In the case of a soil with 100 ppm added nitrogen but no straw addition, 13.7 ppm of the total immobilized labelled nitrogen was remineralized at the end of incubation under optimum moisture conditions, while the corresponding remineralization figure for waterlogged treatment was 14.7 ppm. When rice straw equivalent to 1000 ppm carbon was added to a soil with 100 ppm added N, the remineralization figures under optimum moisture and waterlogged treatments amounted to 19.2 and 14.7 ppm, respectively. Addition of 2500 ppm carbon to soil with 100 ppm added N resulted in the remineralization of immobilized labelled nitrogen equivalent to 32.6, 7.2, 1.0 ppm under optimum moisture, waterlogged, and completely anaerobic conditions, respectively. When the addition of rice straw to a soil with 100 ppm added N was increased to about 4000 ppm carbon, the remineralization amounted to 30.7 ppm under optimum moisture conditions, while little or no remineralization (1.8 ppm) was observed under waterlogged conditions.

It may be noted from the foregoing discussion that the incremental addition of rice straw to soil with 100 ppm added N increased the remineralization of immobilized labelled nitrogen in absolute terms, but decreased it in terms of percentage (Table 1). The increase in net remineralization on addition of straw may be due to enhanced biological activities which, in turn, caused an increased nitrogen turnover. The data on the remineralization of immobilized labelled nitrogen indicate that nitrogen, immobilized during incubation with straw, does not become a homogenous mixture with soil organic matter and that the duration and active life of newly synthesized tissue is short. Earlier, Jansson (1958) and Stewart *et al.* (1963) noted these effects.

The lower values of nitrogen remineralization under waterlogged as compared with optimum moisture conditions are perhaps due to retarded microbial activity. Since a more restricted and less efficient bacterial flora is involved under waterlogged conditions, both mineralization and synthesis are considerably retarded. The effect of microflora on the nitrogen remineralization was more marked under completely anaerobic than under waterlogged conditions.

It is important to note that the values of net remineralization reported in this study are generally higher than those reported by earlier workers. Broadbent and Tyler (1957, 1962) and Broadbent and Nakashima (1965) reported that immobilized nitrogen resists mineralization for rather long periods of time. Jansson (1963) noted that the net mineralization of biologically immobilized nitrogen amounted to about 3.0 to

4.7 percent per year. Broadbent and Tyler (1958) attributed the low recoveries of immobilized nitrogen to the formation of nitrogenous compounds of greater biological stability. Bremner (1955) likewise reported that much of the organically synthesized nitrogen was very resistant to subsequent decomposition. He found that most of this was present in the form of protein, and a smaller fraction was present as amino sugars.

3. Absolute Values of Mineralization and Immobilization

The preceding discussion on nitrogen immobilization-mineralization relationship was primarily based on net mineralization and net immobilization in the biological system. The net changes were measured by following the appearance and disappearance of labelled nitrogen in the inorganic nitrogen pool. However, it may be of interest to consider the absolute turnover rates when two opposing processes are proceeding simultaneously, as in the case of mineralization and immobilization. In the tracer system of the kind employed in this study, calculation of the absolute rate and magnitude of mineralization and immobilization can be made by using the equations of Kirkham and Bartholomew (1955) provided the basic assumptions used in deriving the equations are valid for the system under study. These authors studied two possible integration postulates of the following basic differential equations.

$$\frac{dx}{dt} = m - i,$$

and $$\frac{dy}{dt} = \left[\frac{b-y}{a-x} \bullet m\right] - \left[\frac{y}{x} \bullet i\right]$$

where x = total inorganic (extractable) N
t = time
m = mineralization rate
i = immobilization rate
y = labelled inorganic N
a = total N in system
b = total labelled N

In performing the integration of these equations, Kirkham and Bartholomew considered two cases. In case I, i and m are considered to be constants during the time intervals studied. In case II they are considered proportional to x and y, respectively. Further, case I is applicable if a plot of inorganic nitrogen against time is linear. Case II holds if a plot of inorganic nitrogen versus labelled inorganic nitrogen yields a straight line. An inspection of the data in Figures 3-6 (optimum moisture) indicates that the plot of inorganic nitrogen versus time does not form a straight line for the entire incubation period (0-120 days); however, several segments of the curve representing short time intervals are perhaps sufficiently linear for the equation to be valid. Mineralization and immobilization rates were, therefore, calculated according to the equation derived from the case I postulate.

$$m = \frac{x - x_0}{t} \bullet \frac{\log_e \left[\left(\frac{y}{b} - \frac{x}{a} \right) / \left(\frac{x y_0}{b x_0} - \frac{x}{a} \right) \right]}{\log_e \left(\frac{x_0}{x} \bullet \frac{a - x}{a - x_0} \right)}$$

$$i = m - \frac{x - x_0}{t}$$

Tables 2 and 3 give values of *m* and *i* for various treatment combinations. Rates of nitrogen interchange were much higher during the first 15 days than during the later part of the incubation period, when microbial activity had sufficiently subsided. This was true under all combinations of added carbon and nitrogen. In the absence of straw, mineralization dominated except for the initial eight days, but the immobilization rate was far from negligible, indicating that the two opposing processes were proceeding simultaneously. Calculations for the entire incubation period (0-120 days) indicate a strong prevalence of mineralization. Immobilization comprised about 41 percent of the mineralization.

When straw was added, immobilization of ammonium nitrogen was greatly stimulated, being about 3 to 6 times that of the non-straw treatment. The increase in immobilization was almost proportional to the amount of straw added. It was also indicated that the addition of straw stimulated the mineralization process, although the data for different treatment combinations were not very consistent.

Of special interest, and perhaps importance, is the comparison of turnover rates under aerobic (optimum moisture) and anaerobic conditions (100 ppm N + 2500 ppm C). The data in Table 3 indicate that anaerobic mineralization proceeded at a much higher rate, being about two times the aerobic mineralization, whereas immobilization was dominant under aerobic conditions. Calculations for turnover rates over the entire incubation period (0-120 days) demonstrate that mineralization was 1.35 times higher under anaerobic than under aerobic system; immobilization, however, was slightly higher under the aerobic conditions.

The zero values registered for nitrogen turnover rates, in case of the treatment of 100 ppm N + 4000 ppm C, are due to zero values of *x* (total inorganic nitrogen), indicating no net mineralization or immobilization. These equations do not hold under such conditions; however, a separate treatment of these data is possible to calculate the turnover rates under these conditions (Kirkham and Bartholomew, 1955).

The foregoing discussion on the application of the Kirkham and Bartholomew equations to data obtained indicate that the equations do

TABLE 2.—Rates of nitrogen mineralization and immobilization calculated from equations of Kirkham and Bartholomew (1955) under optimum moisture conditions

Treatment	Time (days)	Mineralization rate (ppm/day)	Immobilization rate (ppm/day)
100 ppm N	0 - 4	2.93	7.29
	4 - 8	0.93	1.20
	8 - 15	0.23	−1.64
	15 - 30	1.00	0.05
	30 - 45	0.08	−0.42
	45 - 60	0.56	0.43
	60 - 90	0.29	−0.31
	90 - 120	0.12	0.15
	0 - 120	0.46	0.19
100 ppm N + 1000 ppm C	0 - 4	2.89	8.97
	4 - 8	−0.70	3.84
	8 - 15	3.79	2.29
	15 - 30	−1.11	−2.20
	30 - 45	0.62	0.20
	45 - 60	0.66	−0.30
	60 - 90	0.05	−0.31
	90 - 120	0.14	0.03
	0 - 120	0.46	0.30
100 ppm N + 4000 ppm C	0 - 4	2.51	13.40
	4 - 8	1.29	7.26
	8 - 15	3.30	7.88
	15 - 30	0.00	0.00
	30 - 45	0.00	0.00
	45 - 90	0.00	−1.28
	90 - 120	0.31	−7.20

TABLE 3.—Rates of nitrogen mineralization and immobilization calculated from the equations of Kirkham and Bartholomew (1955) under optimum moisture and anaerobic conditions

Treatment	Time (days)	Mineralization rate (ppm/day)	Immobilization rate (ppm/day)
100 ppm N + 2500 ppm C (optimum moisture)	0 - 4	2.11	11.37
	4 - 8	1.31	6.23
	8 - 15	−1.00	2.78
	15 - 30	0.10	2.22
	30 - 45	0.30	−0.45
	45 - 60	0.62	−0.25
	60 - 90	−0.61	−2.12
	90 - 120	0.13	−0.20
	0 - 120	0.58	0.85
100 ppm N + 2500 ppm C (waterlogged anaerobic)	0 - 4	5.57	12.00
	4 - 8	3.16	5.74
	8 - 15	−0.04	−0.03
	15 - 30	1.18	0.96
	30 - 60	0.40	−0.04
	60 - 90	0.31	0.06
	90 - 120	0.11	−0.14
	0 - 120	0.78	0.82

give a general picture of nitrogen mineralization and immobilization in absolute terms but are not necessarily always in strict conformance with the biological events taking place in the system. The application of these equations was not tested under waterlogged conditions due to the heavy losses of nitrogen encountered under these conditions. Equations must be corrected to account for nitrogen loss from the system in order to calculate the nitrogen turnover rates under waterlogged conditions.

The second postulate (case II) of Kirkham and Bartholomew equations based on the assumption that mineralization and immobilization rates are proportional to labelled organic and inorganic nitrogen, respectively, was not found applicable to these data.

C. Distribution of Applied Nitrogen into Different Chemical Fractions of Soil Nitrogen

1. Chemical Distribution of Native Soil Nitrogen in Crowley Silt Loam

The initial distribution of native soil nitrogen into different chemical fractions is presented in Figure 8a. Amino acid N and hydrolyzed ammonium N comprised the largest fraction (73 percent) of total soil nitrogen, while a relatively much smaller fraction (27 percent) was constituted by other organic and inorganic fractions. Amino acid N dominated all the fractions isolated and accounted for about 45 percent of the total soil nitrogen. Hydrolyzed ammonium N, representing the nitrogen that was released by alkaline aeration of acid hydrolyzate, constituted more than one-fourth (28 percent) of the total nitrogen. The amount of nitrogen found in the amino sugar fraction was small, amounting to about 5 percent of total soil nitrogen. Humin N fraction accounted for 20 percent of total nitrogen, with about twice as much in the insoluble humin N (14 percent) as in the soluble humin N fraction (6 percent). The amount of inorganic nitrogen present in the exchangeable N fraction was the least (2 percent) among the various fractions isolated. Non-exchangeable ammonium N was not determined, since this fraction was not considered to be active in the nitrogen transformations studied here. It may be noted from the foregoing paragraph that the chemical distribution of soil nitrogen in Crowley silt loam followed the same general distribution pattern of soil nitrogen as was pointed out in the preceding review of nitrogen transformations in the soil. Relatively low figures for amino sugar N may be due to the partial destruction of amino sugars during the acid hydrolysis process. Stevenson (1957) found that losses of glucosamine were in the order of 12.5 and 15.9 percent when hydrolyzed in 6 *N* HCl for six and nine hours, respectively. Extrapolating these losses to 16-hour hydrolysis time, Cheng and Kurtz (1963) estimated that about one-fourth of the amino sugars in the hydrolyzate would be destroyed. Further, they reported that the nitrogen from partially destroyed amino

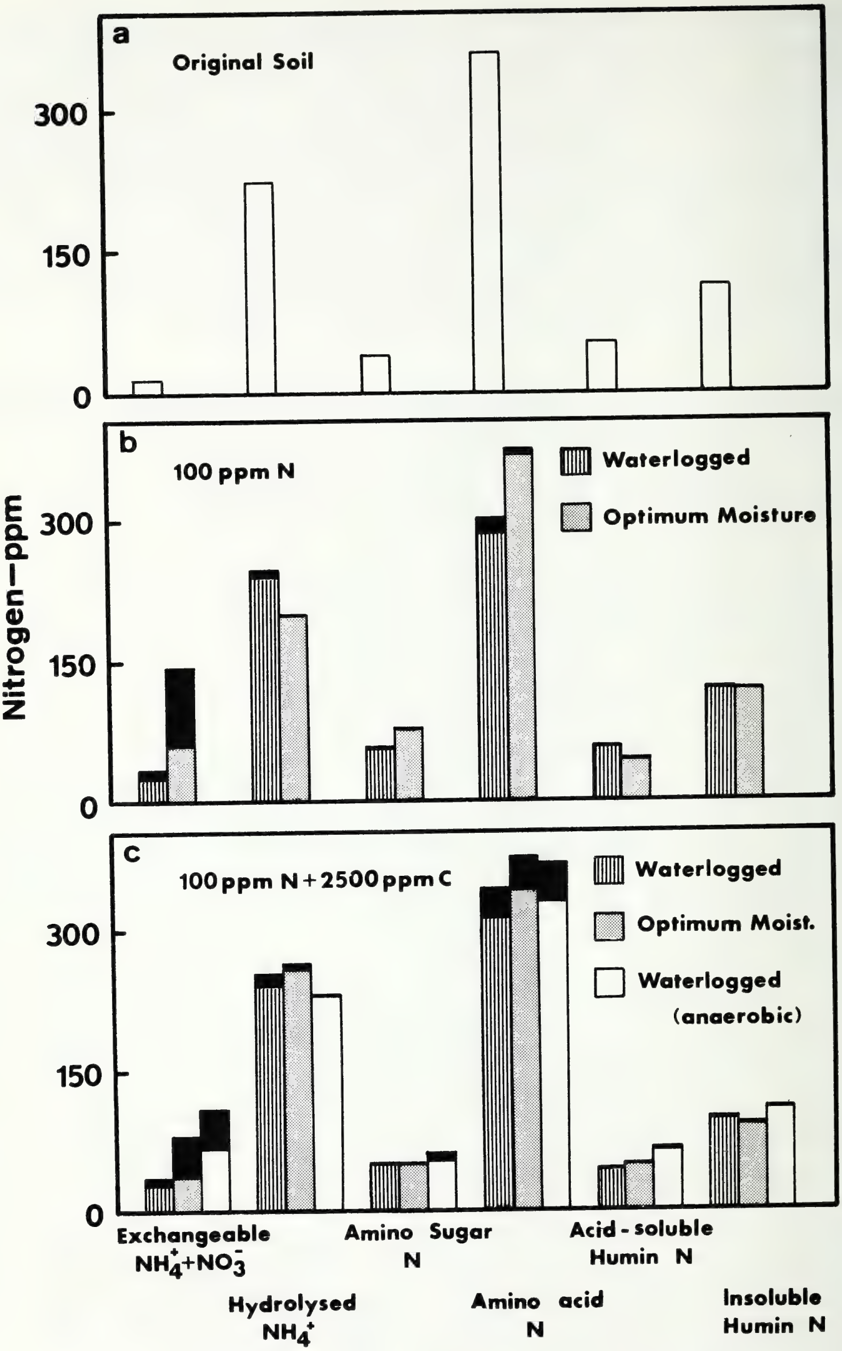

Figure 8.—Distribution of applied (black shaded area) and native soil nitrogen into different chemical fractions at the end of four months' incubation period.

acids and amino sugar components, and that partially released from fixed ammonium during the process of hydrolysis might constitute a part of hydrolyzed ammonium fraction.

2. Chemical Distribution of Applied Nitrogen in Soil

The data in Figure 9a represent the distribution of applied nitrogen (100 ppm N) in soil incubated without added straw under waterlogged and optimum moisture conditions. Under optimum moisture conditions, 84 percent of the applied ammonium stayed in the exchangeable fraction. Of the remaining 16.0 percent, only 11.9 percent was recovered in the organic pool, indicating that 4.1 percent of the applied nitrogen was not accounted for in the various fractions isolated. The distribution of labelled nitrogen within the organic pool showed that about twice as much labelled nitrogen moved into the amino acid fraction as moved into all other organic fractions combined. Relatively much smaller amounts (about 2.2 percent) of applied N entered the hydrolyzed ammonium fraction. Only trace amounts of labelled nitrogen were recovered in amino sugar and humin N fractions. In terms of percentage distribution within the organic pool, about 60 percent of the immobilized labelled N was recovered in the amino acid components, while about 5.5 percent moved into the amino sugar fraction. These two fractions, together with hydrolyzed ammonium N, contained more than 80 percent of the immobilized labelled nitrogen.

The distribution of added nitrogen within the organic pool of the waterlogged treatment was remarkably consistent with that of the optimum moisture treatment. At the end of the incubation period, 16.1 percent of the applied nitrogen had been converted to amino acid N as compared with 7.5 percent which had moved into other organic fractions, indicating that the immobilization of applied nitrogen was twice as much in amino acid fraction as in other organic fractions. Appreciable amounts (about 5.1 percent) of applied nitrogen were detected as hydrolyzed ammonium N. Only trace amounts of labelled N moved into amino sugar and humin N fractions. However, the most important feature of the waterlogged treatment was the remarkably lower recoveries of labelled nitrogen from the exchangeable fraction under waterlogged than under optimum moisture conditions. Approximately 11.4 percent of the labelled nitrogen was found in the exchangeable inorganic fraction under waterlogged conditions, as compared with 84.1 percent recovered under optimum moisture conditions. An account of labelled nitrogen in the various nitrogen fractions isolated indicates that about 65 percent of the applied nitrogen was not accounted for under waterlogged conditions. This loss of applied ammonium was attributed to the possible mechanism of oxidation and subsequent denitrification of ammonium in waterlogged soils and is discussed in detail in a later section.

The results on the distribution of applied nitrogen within the organic pool are in close agreement with the findings of Cheng and Kurtz

(1963), Stewart *et al.* (1963), and IRRI Annual Report (1965), who likewise reported that organic fractions such as amino acid N and hydrolyzed ammonium N were the most important in terms of immobilization. It was also indicated (IRRI Annual Report, 1965) that considerable losses of nitrogen occurred under flooded conditions.

The distribution of applied ammonium N (100 ppm) into different

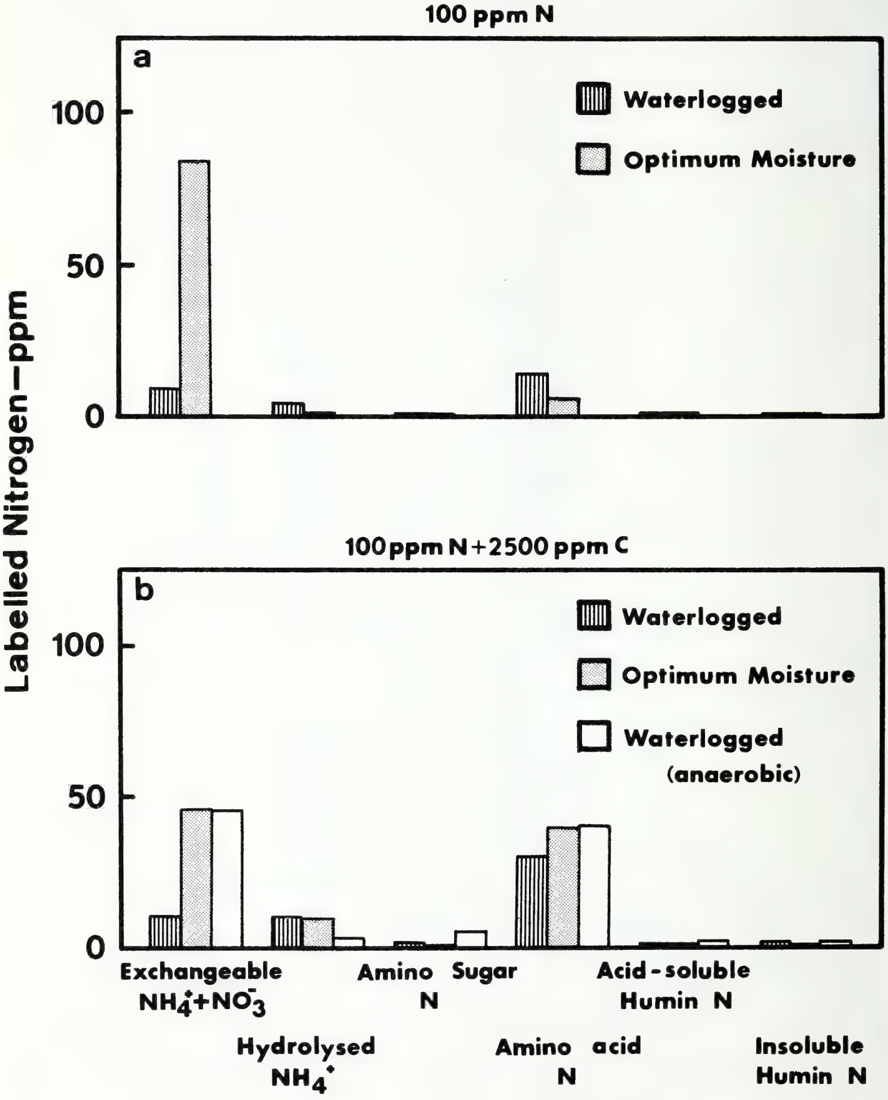

Figure 9.—Distribution of applied nitrogen (100 ppm) into different chemical fractions of soil nitrogen at the end of four months' incubation period as determined by isotope analysis.

chemical fractions of soil nitrogen was also studied in soil incubated with added rice straw (2500 ppm C) and maintained under optimum moisture, waterlogged, and waterlogged-anaerobic (air replaced with argon) conditions for a period of four months. Figure 9b represents the amounts of applied nitrogen found in the different chemical fractions isolated at the end of the incubation period under various conditions of aeration and moisture. Appreciably higher amounts of applied nitrogen became immobilized in the presence of added straw than in its absence. The percentage of applied nitrogen recovered in the combined organic pool was 46.8, 52.8, and 55.0 percent under waterlogged, optimum moisture, and anaerobic conditions, respectively. Despite the greater nitrogen immobilization in the presence of added straw, the general distribution pattern of different chemical fractions within the organic pool was about the same as was earlier observed without added straw. In general, under all conditions of aeration and moisture, approximately two to three times as much fertilizer nitrogen entered the amino acid fraction as entered the other organic fractions combined. For example, under waterlogged conditions 30.1 percent of the applied nitrogen was incorporated into the amino acid fraction as compared with only 16.6 percent incorporated into other fractions. Under optimum moisture conditions 39.6 percent of the applied nitrogen was immobilized into amino acid components while only 13.1 percent moved into all the other fractions combined. Similarly, under anaerobic conditions 40.6 percent of the applied nitrogen was immobilized into the amino acid components compared with 14.4 percent immobilized into the other organic fractions. This indicates that the relative distribution of immobilized labelled nitrogen into the amino acid and the other organic fractions combined was about the same under the rather extreme conditions of aeration and moisture used in this study. The distribution of applied nitrogen in the other organic fractions was about the same under the different aeration and moisture conditions. It is important to note that together the amino acid N, hydrolyzed ammonium N, and amino sugar N fractions constituted more than 90 percent of the total immobilized labelled nitrogen, irrespective of the aeration and moisture treatment. Only small amounts of fertilizer N entered the soluble and insoluble humin N fractions.

An important feature of this study was the remarkably lower amounts of fertilizer N recovered in the exchangeable fraction under waterlogged conditions. About 10.6 percent of the applied nitrogen was detected in the exchangeable fraction under waterlogged conditions, as compared with about 45.9 and 44.9 percent found under optimum moisture and anaerobic conditions, respectively. Total labelled nitrogen recovered from various chemical fractions isolated under the three aeration and moisture conditions indicates that a large amount, equivalent to about 42.6 percent, was lost under the waterlogged conditions. The loss of applied nitrogen under optimum moisture and completely anaerobic conditions was relatively insignificant. The tremendous loss under waterlogged conditions was attributed to the oxidation of ammonium and subsequent denitrification in waterlogged soils. The nitrogen loss under the anaerobic and optimum moisture conditions was well within the experimental error.

While further studies are needed, the significant conclusions from the foregoing results may be summarized as follows: (1) Amino acid N, hydrolyzed ammonium N, and amino sugar N were the most important organic nitrogen fractions in terms of nitrogen immobilization. Together these three fractions contained about 90 percent of the immobilized labelled nitrogen under all conditions of aeration and moisture; (2) about two to three times as much added nitrogen entered the amino acid fraction as entered the other organic fractions; (3) the addition of straw increased the rate of nitrogen immobilization but did not alter the distribution pattern of added nitrogen within the soil organic pool; (4) no significant difference in the distribution of added nitrogen into the various organic fractions, was noted between the waterlogged treatment and the completely anaerobic treatment; however, considerable losses of nitrogen occurred under waterlogging in contrast to no loss under anaerobic conditions.

D. Losses of Applied and Native Nitrogen in a Waterlogged Soil System

The data presented in Figure 10 show the distribution of applied nitrogen (100 ppm) into inorganic and organic fractions. The area labelled as "unaccounted for N" represents the magnitude of nitrogen loss from applied $(^{15}NH_4)_2SO_4$ in a waterlogged soil system incubated for a period of four months. Large losses of applied nitrogen occurred under continuously waterlogged conditions. These losses were most pronounced in the absence of added straw but decreased progressively as the amount of added straw increased. In the case of soil treated with 100 ppm ammonium N in the absence of added straw, a tremendous loss, amounting to 68 percent of the labelled nitrogen originally applied to soil, occurred after an initial lag period of 15 days. The rate of nitrogen loss was at a maximum during the time interval between 15 and 60 days after incubation (1.3 ppm per day for about 45 days) and decreased rapidly as the incubation period proceeded. About 85 percent of the total loss occurred during the first two months, with only a small loss (15 percent) occurring during the last part of the incubation period. It is important to point out that at the end of the incubation period only 11.4 percent of the applied nitrogen was present in the inorganic fraction, 20.4 percent was immobilized into the organic phase, and the remaining 68.2 percent was lost from the system.

Addition of rice straw to soil with 100 ppm ammonium N decreased both the rate and magnitude of nitrogen loss. The decrease in nitrogen loss was proportional to the increase in nitrogen immobilization, which in turn was proportional to the amount of straw added.

Interpretation of the data in Figure 10 indicates that the addition of straw at a rate equivalent to 1000 ppm carbon caused nitrogen loss to decrease and nitrogen immobilization to increase. About 58.6 percent of the applied nitrogen was lost during the four-month incubation period in the presence of straw, as compared with 68.2 percent nitrogen lost in the absence of straw. Maximum loss of nitrogen at a rate of about 0.9 ppm per day occurred during the time interval marked by the linear portion of the curve (15-60 days) and accounted for about 85 percent of the total loss. When the rates of added straw were increased to 2500 ppm and 4000 ppm carbon, the loss of nitrogen from applied $(^{15}NH_4)_2SO_4$ was decreased to 43.0 ppm and 34.8 ppm, respectively. This indicates that the addition of straw equivalent to 4000 ppm carbon reduced the nitrogen loss to one-half of that encountered without added straw. However, it is important to note that, notwithstanding the decrease in nitrogen loss by incremental additions of added straw, the amount of available nitrogen (extractable ammonium + nitrate) left in the inorganic pool was about the same (6 to 12 ppm) at the end of the incubation period under all combinations of added carbon and nitrogen. This indicates that the decrease in nitrogen loss from additional increments of added straw was primarily caused by the increased immobilization of inorganic nitrogen into the organic phase. The vigorous

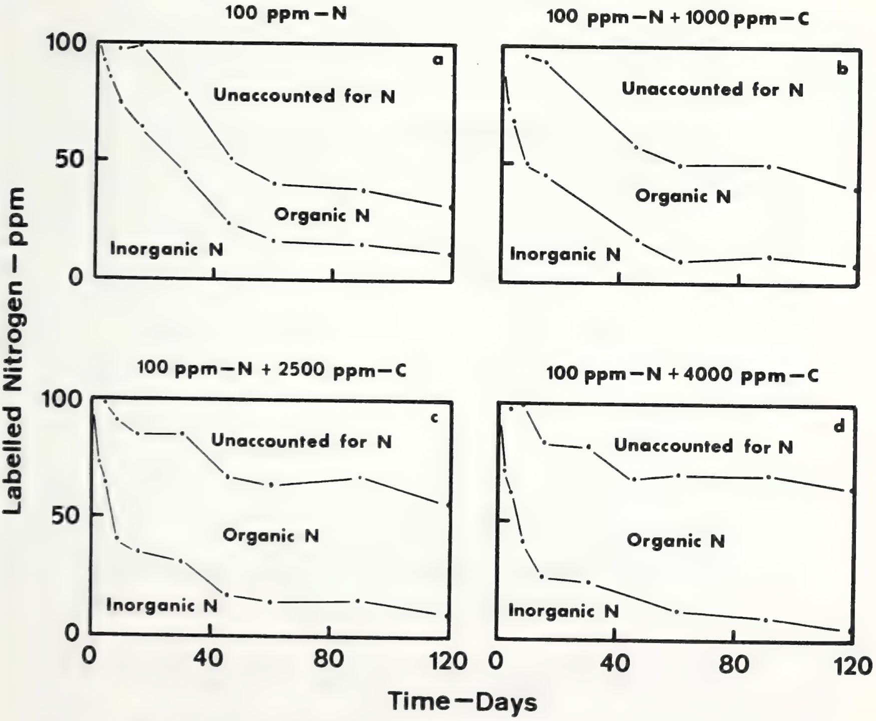

Figure 10.—Losses of nitrogen from applied $(^{15}NH_4)_2SO_4$ in a waterlogged soil.

net immobilization, with little or no nitrogen loss during the first 15 days of incubation, provides evidence to this effect. The close parallel between the rate of nitrogen loss and the amount of inorganic nitrogen present (Figure 10) suggests that after an initial lag period of 14 days, when immobilization was predominant, the nitrogen loss was directly proportional to the concentration of ammonium present in the inorganic pool. Further, Figure 11, depicting the distribution of applied and soil inorganic nitrogen in the sample profile, indicates that about 75 percent of the applied nitrogen was present within 1.5 cm of the surface layer. This in turn indicates that the ammonium at or near the soil-water interface in a waterlogged soil system is fairly unstable and is constantly subjected to loss from the system through a mechanism of nitrification and subsequent denitrification. A detailed discussion of this mechanism will be given later in this section.

Figure 10 can be interpreted to account for nitrogen loss only from the labelled applied nitrogen and does not include the loss of nitrogen from the soil nitrogen mineralized during the four-month incubation period. A quantitative evaluation of these losses is rendered difficult by the fact that nitrogen mineralization and nitrogen loss in waterlogged

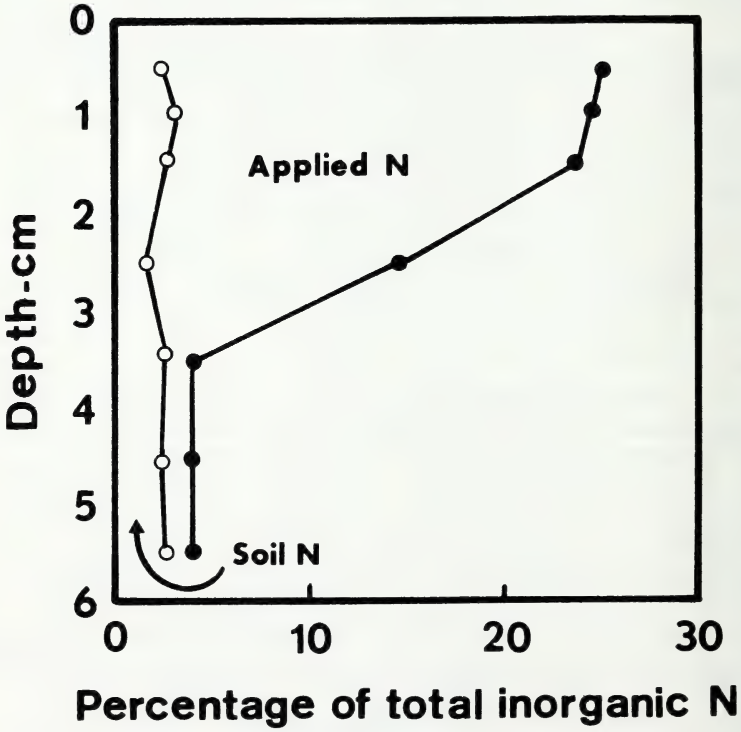

Figure 11.—Distribution of applied and soil inorganic nitrogen in a sample profile.

soils often proceed simultaneously. However, an evaluation of the total nitrogen loss from the soil system should provide an estimate of loss of native soil nitrogen.

Figure 12 shows the changes in total nitrogen for the treatments maintained under optimum moisture and waterlogged conditions at various levels of straw in combination with 100 ppm N as $(^{15}NH_4)_2SO_4$. Little or no nitrogen was lost under optimum moisture, in contrast with the large loss of nitrogen that occurred under continuously waterlogged conditions. The decrease in the total nitrogen content became evident about 20 or 30 days after waterlogging and proceeded continuously for the rest of the incubation period. The difference in total nitrogen between optimum moisture and waterlogged treatments provides an estimate of nitrogen loss caused solely by waterlogging. In the absence of added straw about 93.0 ppm nitrogen, equivalent to about 9.8 percent of total nitrogen, was lost during the four-month incubation period. Losses of a slightly higher magnitude, amounting to 97.8 ppm nitrogen or 10.1 percent of the total nitrogen, were observed in the case where the straw was added at a rate of 1000 ppm carbon. Addition of straw at higher rates, 2500 ppm and 4000 ppm carbon, caused an appreciable decrease in the nitrogen loss from the waterlogged system. About 63.2 ppm nitrogen, representing 6.8 percent of the total nitrogen, was lost in the case of 2500 ppm carbon treatment, while 83.5 ppm nitrogen, which was equivalent to 8.7 percent of total nitrogen, was lost in the case where 4000 ppm carbon in the form of rice straw was added. It should be kept in mind that these losses include the labelled nitrogen lost from the system.

At this stage, it is important to discuss the mechanism accounting for these large losses of applied ammonium N and soil nitrogen in a waterlogged soil system. The losses are apparently too great to be accounted for by direct volatilization or fixation into clay lattices under these experimental conditions. Furthermore, the comparison between waterlogged and optimum moisture treatments invariably suggests that the loss of nitrogen in soil is due solely to waterlogging. This leads to the strong possibility of nitrogen loss through a special process prevailing in waterlogged soils in which ammonium N is oxidized to nitrate N in the surface oxidized layer of soil. The nitrate thus produced is lost upon entry into the underlying reduced layer through denitrification to nitrogen gas (N_2) and nitrous oxide (N_2O). The magnitude of this nitrogen loss through denitrification in such a system will be dependent on the concentration of ammonium in or near the surface oxidized layer, the depth of the surface oxidized layer, and the movement or diffusion of nitrate into the underlying reduced layer. High concentrations of ammonium applied in the form of fertilizer or produced during the mineralization of organic nitrogen in the surface oxidized layer would, therefore, cause pronounced nitrogen loss through the nitrification of ammonium in a waterlogged soil system of the kind employed in this experiment. Figure 11 indicates that about 75 percent of the applied nitrogen was present within 1.5 cm of the surface layer and was, therefore, exposed to the process of nitrogen loss. These losses could be minimized by deep placement of the added ammonium in the reduced layer or by treating the soil with a nitrification inhibitor.

To further illustrate that the nitrogen loss in a waterlogged soil system did occur through the proposed mechanism of nitrification and

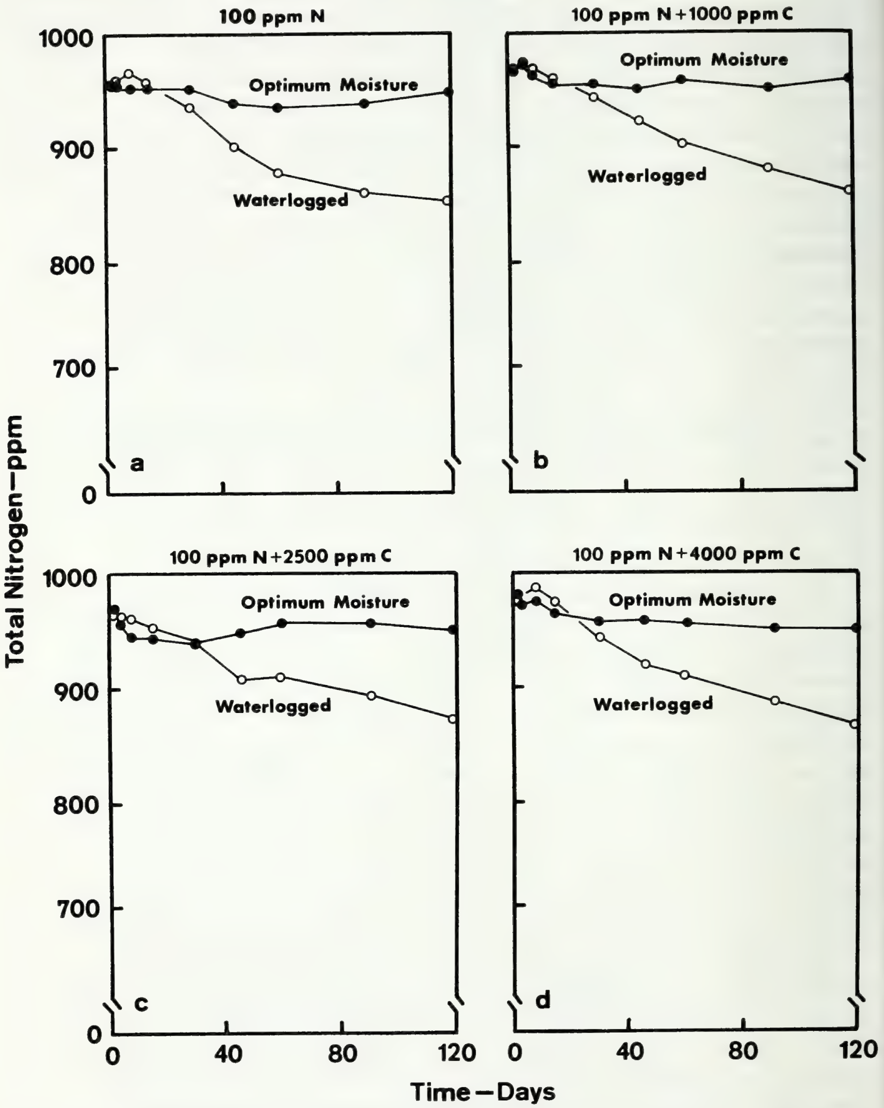

Figure 12.—Changes in total nitrogen under waterlogged and optimum moisture conditions in soils receiving 100 ppm ammonium nitrogen and varying amounts of carbon as rice straw.

subsequent denitrification, the data on nitrogen loss under different aeration and moisture conditions may be considered in Figure 13. Negligible or no nitrogen loss from applied $(^{15}NH_4)_2SO_4$ under completely anaerobic conditions (air replaced with argon), maintained either under waterlogged or at optimum moisture conditions, compared with 43 per cent nitrogen loss in a corresponding waterlogged system (air not replaced with argon) emphasizes the strong influence of the surface oxidized layer on nitrogen loss in the latter system. Likewise, no nitrogen was lost in a completely aerobic system (optimum moisture). This indicates that the establishment of permanent layers of oxidized soil and reduced soil, as in a waterlogged soil system, is necessary for nitrogen loss to occur from ammonium applied in the form of fertilizer or produced through mineralization of organic nitrogen.

The significant conclusions from this study may be summarized as follows: (1) Severe losses of ammonium nitrogen, either applied in the form of fertilizer or mineralized during the decomposition of organic matter, occurred as a result of waterlogging; (2) about 85 percent of the total loss from the applied nitrogen occurred during the first two months of incubation; (3) the losses were more pronounced in the

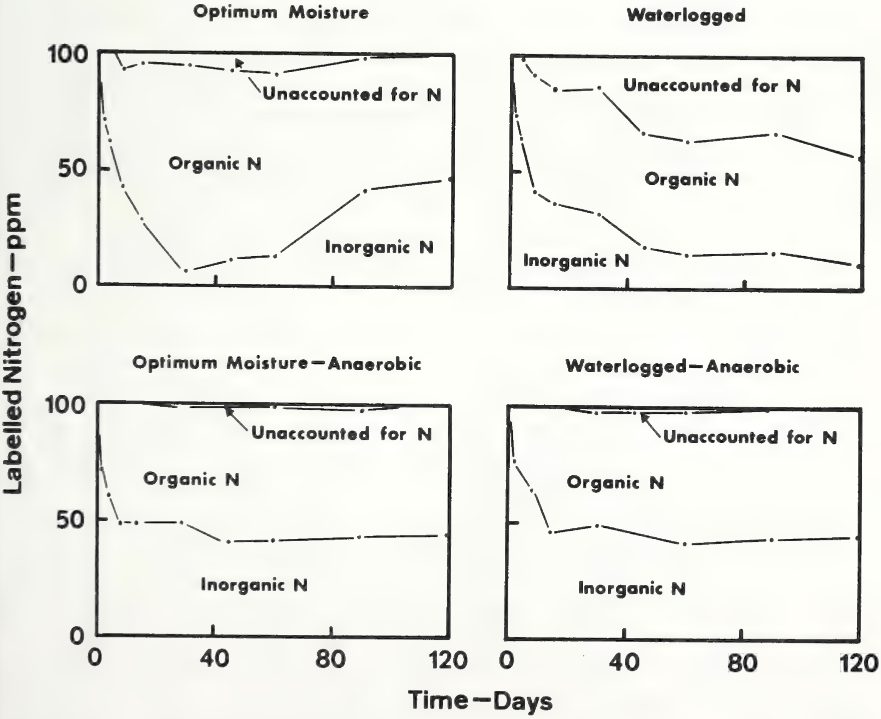

Figure 13.—Distribution of applied $(^{15}NH_4)_2SO_4$ nitrogen under different aeration and moisture conditions.

absence of added straw than in its presence; (4) the nitrogen loss from applied ammonium was proportional to the amount of ammonium present at any one time except for the initial 15-day period, when immobilization was dominant; (5) although the addition of straw considerably reduced the amount of nitrogen loss from the waterlogged soil system, the amount of plant available nitrogen (extractable ammonium + nitrate) left in the inorganic pool was about the same under all combinations of added carbon and nitrogen; (6) negligible or no nitrogen loss occurred from applied $(^{15}NH_4)_2SO_4$ under completely anaerobic or aerobic conditions; (7) the process of nitrification and subsequent denitrification apparently accounted for large losses of applied and soil nitrogen under waterlogged conditions.

It should be stressed, however, that the present results refer to a restricted waterlogged system confined to a 100-gram soil system incubated under laboratory conditions. Therefore, conclusions cannot safely be drawn on the magnitude of nitrogen loss that would be encountered under field conditions. It will be expected that under field conditions the loss from ammonium nitrogen may be reduced considerably due to continuous ammonium uptake by the rice plant, thereby leaving relatively lower amounts of ammonium available for the process of nitrogen loss. On the other hand, it is also possible that the oxidized rhizosphere of rice roots may even accelerate the process of nitrification and denitrification. It is generally accepted that nitrogen, regardless of the form applied, is less efficiently utilized by rice than by other grain crops, presumably as a result of a greater loss of nitrogen from the flooded rice soil. Further studies are needed to understand the impact of the growing rice plant on the magnitude of nitrogen loss in a waterlogged soil system.

E. Losses of Nitrogen Under Alternate Submergence and Drying Conditions

The results of this experiment representing the changes in nitrogen measured at the end of each submergence-drying half cycle are illustrated in Figures 14 and 15. Changes in labelled inorganic nitrogen at the end of each complete cycle are shown in Figure 15. Total nitrogen losses as well as losses from applied nitrogen, over a submergence and drying incubation period of four months, are summarized in Table 4. Submergence and drying of the soil samples resulted in a tremendous loss of total and applied nitrogen regardless of the number of cycles the soil underwent. About 158 ppm and 135 ppm nitrogen, accounting for 16.6 percent and 14.3 percent of the total nitrogen, was lost respectively from 30-day and 40-day submergence and drying cycle treatments. Slightly higher losses of nitrogen under the 30-day treatment during the same incubation period may have been due to the one additional submergence and drying cycle. Another important feature of this loss is that much more nitrogen was lost from the soil as a result of submergence and drying than was actually mineralized in a correspond-

TABLE 4.—Changes in total and labelled nitrogen under alternate submergence and drying conditions

Treatment	Form of nitrogen	Nitrogen - ppm			Percent loss
		At beginning of experiment	At end of experiment	Net loss	
Submergence and drying, 30-day cycle	Labelled inorganic N	100.0	43.4	56.6	56.6
	Total N	955.4	796.8	158.6	16.6
Submergence and drying, 40-day cycle	Labelled inorganic N	100.0	46.8	53.2	53.2
	Total N	945.4	809.8	135.6	14.3

ing treatment under continuous optimum moisture conditions. Since the most probable pathway of nitrogen loss involves the formation of nitrate and its subsequent denitrification, it can be inferred that more mineralization of organic nitrogen occurred under alternate waterlogged and drying conditions than in a continuously aerated soil. The effect of alternate submergence and drying on the increased mineralization of organic nitrogen had long been indicated by Russell and Hatchinson (1913), and Mitsui (1954) and subsequently confirmed by Harada (1959, 1968), and Patrick and Wyatt (1964).

Of the 100 ppm applied ammonium N, about 43 to 47 percent was immobilized and the remaining 53 to 57 percent was lost, so that, towards the end of the incubation period, practically no labelled nitrogen was detected in the inorganic nitrogen pool. This indicates that inorganic nitrogen is highly unstable under moisture fluctuations of the type described.

A close examination of Figures 14 and 15 clearly shows that most of these losses occurred during the first two submergence and drying cycles. From the quantitative evaluation of Figure 13 it was estimated that about 81 to 87 percent of the total nitrogen loss occurred during the first two submergence and drying cycles, with a much smaller loss occurring during the subsequent cycles. The percentage loss during the first two cycles was relatively higher under the 40-day cycle treatment (87 percent) than under the 30-day cycle (81 percent). This may be due to the longer duration of each drying and submergence half cycle, resulting in more nitrate formation and hence more subsequent denitrification. Similarly, the interpretation of data in Figure 15 indicates that 92 to 99 percent of the total loss from the applied nitrogen occurred during the first two cycles.

These results with a tracer technique confirm, in general, the earlier

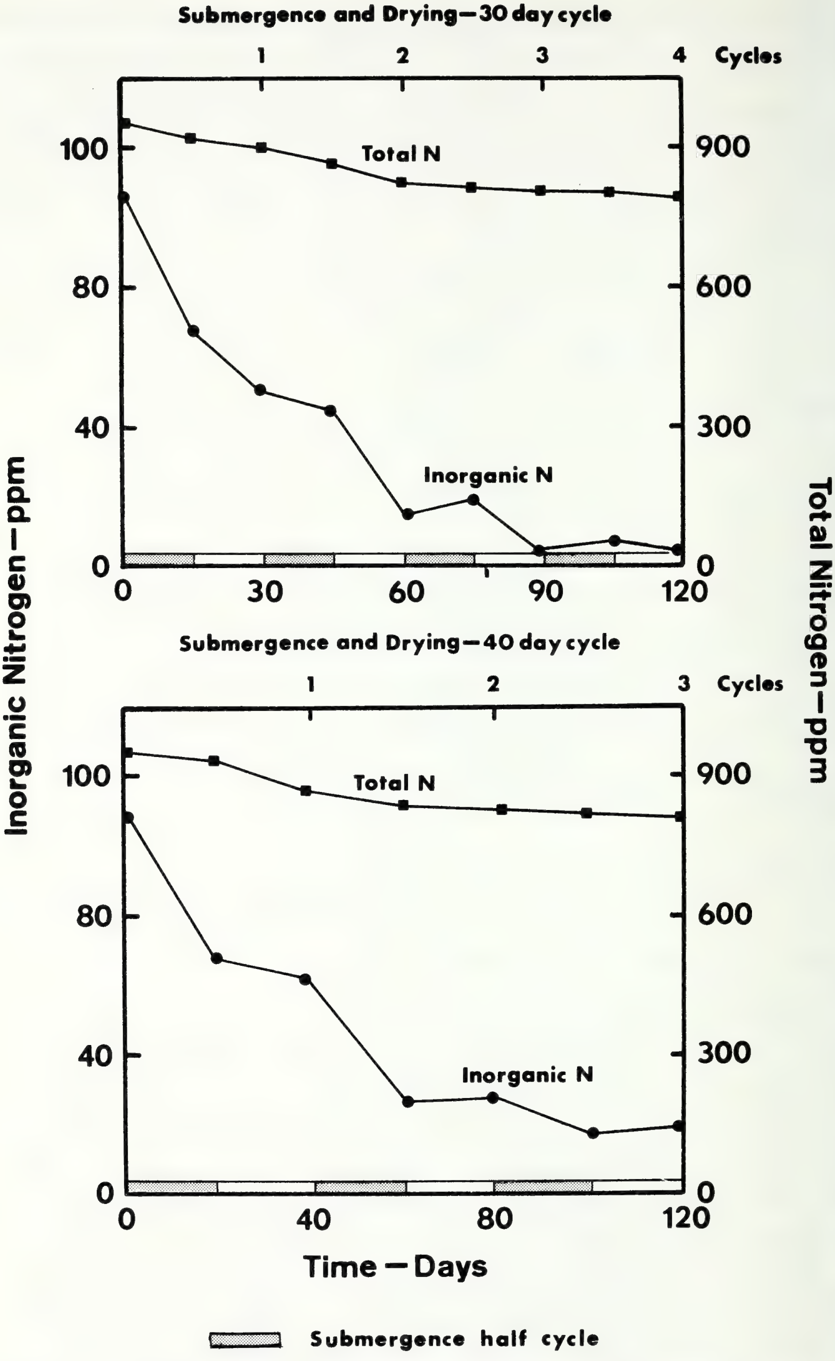

Figure 14.—Changes in total and inorganic nitrogen under alternate submergence and drying conditions.

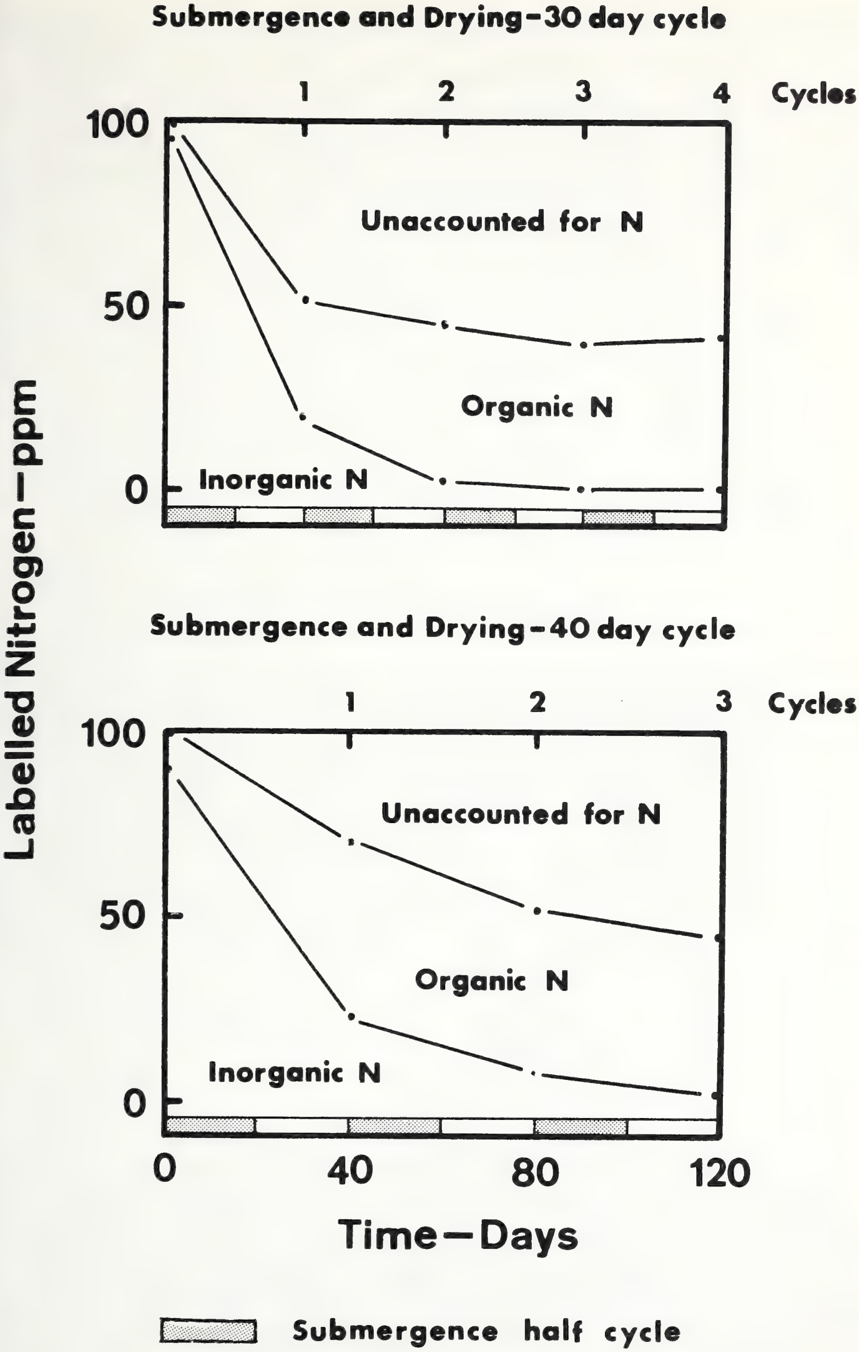

Figure 15.—Changes in labelled nitrogen under alternate submergence and drying conditions.

work of Patrick and Wyatt (1964), who likewise showed that large losses of total nitrogen occur during the first two cycles of submergence and drying. In addition, the results of this study clearly demonstrate the highly unstable nature of the inorganic nitrogen pool, and particularly that of applied ammonium N, under alternate submergence and drying conditions. Out of 45 percent of ammonium N left after the initial immobilization, only trace amounts (1 to 3 percent) were detected in the inorganic pool at the end of the incubation. Further, interpretation of the ^{15}N data (Figure 14) clearly demonstrates the role of added rice straw in conserving the added ammonium N against losses from moisture fluctuations. As indicated earlier, about 43 percent of applied nitrogen was immobilized into the organic phase, and apparently little of this immobilized fraction was remineralized during the four-month incubation period. It is possible that in the absence of added rice straw most of this immobilized nitrogen would otherwise have been lost due to the submergence and drying treatment. Finally, the data indicate that increasing the number of submergence and drying cycles within the same incubation period might increase the loss of total nitrogen.

SUMMARY AND CONCLUSIONS

Tracer studies on nitrogen transformations were made in Crowley silt loam incubated under laboratory conditions for a period of four months. Ammonium sulfate enriched with ^{15}N was used as a tracer to investigate the fate of applied nitrogen in waterlogged, optimum moisture, and anaerobic (air replaced with argon) soil systems. Studies were also made on the mineralization of organic nitrogen under waterlogged and optimum moisture conditions. Tracer investigations were mainly concerned with the immobilization-mineralization relationship, remineralization of immobilized labelled nitrogen, absolute nitrogen turnover rates, and distribution of applied nitrogen into different chemical fractions. Nitrogen losses from applied $(^{15}NH_4)_2SO_4$ and native soil nitrogen were measured in a waterlogged soil system and under successive cycles of submergence and drying.

The data on the mineralization rates of organic nitrogen at various C:N ratios (15:1, 21:1, 35:1, and 92:1) of added plant material indicated that the inorganic nitrogen accumulated at a higher rate under waterlogged than under optimum moisture conditions. The difference between the two moisture regimes was more pronounced at the higher C:N ratios (21:1, 35:1) than at a lower C:N ratio (15:1), and persisted for about two months of incubation. This was followed by a gradual decline in ammonium accumulation under waterlogged conditions in contrast with a rapid increase in inorganic nitrogen under optimum moisture conditions. The initial rapid increase and subsequent decrease in ammonium accumulation under waterlogged conditions as compared with optimum moisture conditions were attributed to the low nitrogen requirements of anaerobic metabolism and to subsequent nitrogen loss, respectively.

Tracer studies on the immobilization and mineralization relationship at various levels of added straw revealed that, regardless of the moisture regime and aeration treatment, the rate of net immobilization increased progressively as the amount of added straw increased. Further, the tracer data indicated that while net immobilization proceeded much more rapidly under aerobic (optimum moisture) than under anaerobic conditions, net mineralization tended to dominate under anaerobic conditions. A precise estimate of the net mineralization of organic nitrogen under waterlogged conditions was seriously impaired by large losses of applied and native nitrogen under these conditions. However, the data on organic nitrogen did indicate that net mineralization values for the waterlogged system were of about the same magnitude as those under optimum moisture conditions, or slightly less.

Remineralization of immobilized labelled nitrogen was, in general, a slow process. The rate, however, was most significant under optimum moisture and least pronounced under anaerobic conditions. The waterlogged treatment was intermediate between the two. The differences in the rate and magnitude of remineralization under optimum moisture and waterlogged conditions widened as the ratio between added carbon and nitrogen increased.

Absolute nitrogen turnover rates under optimum moisture and anaerobic conditions were calculated from the equations of Kirkham and Bartholomew (1955). Mineralization dominated in the non-straw treatment, but immobilization was far from negligible, indicating that the two opposing processes were proceeding simultaneously. Additions of straw stimulated immobilization to about 3 to 6 times that of the non-straw treatment. Anaerobic mineralization proceeded at a higher rate and was about 2 times that of aerobic mineralization, while, on the other hand, the immobilization was comparatively higher under aerobic conditions. In conclusion, the equations did give a general picture of the absolute nitrogen turnover rates but were not necessarily in strict conformance with the biological events taking place in the system.

The distribution of applied nitrogen into different chemical fractions of soil nitrogen indicated that the amino acid N, hydrolyzed ammonium N, and amino sugar N were the most important organic nitrogen fractions in terms of nitrogen immobilization. Together these three fractions contained about 90 percent of the immobilized labelled nitrogen under all conditions of aeration and moisture (waterlogged, optimum moisture, anaerobic). About 2 to 3 times as much added nitrogen entered the amino acid fraction as entered the other organic fractions. Only small amounts of the labelled N moved into the humin N fraction. Addition of straw increased the immobilization of labelled nitrogen into organic fractions but did not alter the relative distribution of immobilized nitrogen within the different fractions of the organic pool. Large amounts of applied nitrogen were lost under waterlogged conditions in contrast with practically no loss under optimum moisture and anaerobic conditions. Consequently, at the end of the incubation period only small amounts of the applied nitrogen were detected in the inorganic pool under waterlogged conditions as compared with the large amounts present under optimum moisture and anaerobic conditions.

Severe losses (80 to 100 ppm) of ammonium N, either applied in the form of fertilizer at the soil-water interface or mineralized during the decomposition of organic matter, occurred as a result of waterlogging. About 85 percent of the total loss from the applied nitrogen occurred during the first two months of incubation. The losses were more pronounced in the absence of added straw than in its presence. At the end of the four-month incubation period about 68 percent of the applied nitrogen was lost in the non-straw treatment as compared with about 43 percent in the presence of added straw (2500 ppm C). However, the amounts of available nitrogen (ammonium + nitrate) left in the inorganic pool were about the same under all levels of added carbon, indicating that the reduction in nitrogen loss by added straw resulted from the immobilization of inorganic nitrogen into the organic phase. On the contrary, little or no nitrogen loss was observed under the anaerobic and optimum moisture conditions. Nitrogen loss under waterlogged conditions was very likely caused by nitrification of ammonium to nitrate at the surface oxidized layer and subsequent diffusion and denitrification of nitrate in the underlying reduced zone.

Large losses (14 to 16 percent) of the total soil nitrogen occurred under successive cycles of submergence and drying, and well above 80 percent of the total loss occurred during the first two submergence and drying cycles. Tracer data revealed that applied ammonium nitrogen was highly unstable under these conditions, so that only a trace amount of the applied nitrogen was detected at the end of the four-month incubation. More frequent moisture fluctuations within the same incubation period increased the loss of native soil nitrogen but did not appreciably affect the loss of applied N. Much more nitrogen was lost from the soil as a result of submergence and drying than was actually mineralized as ammonium + nitrate under the corresponding optimum moisture conditions, indicating greater mineralization of soil organic nitrogen under submergence and drying than under optimum moisture conditions.

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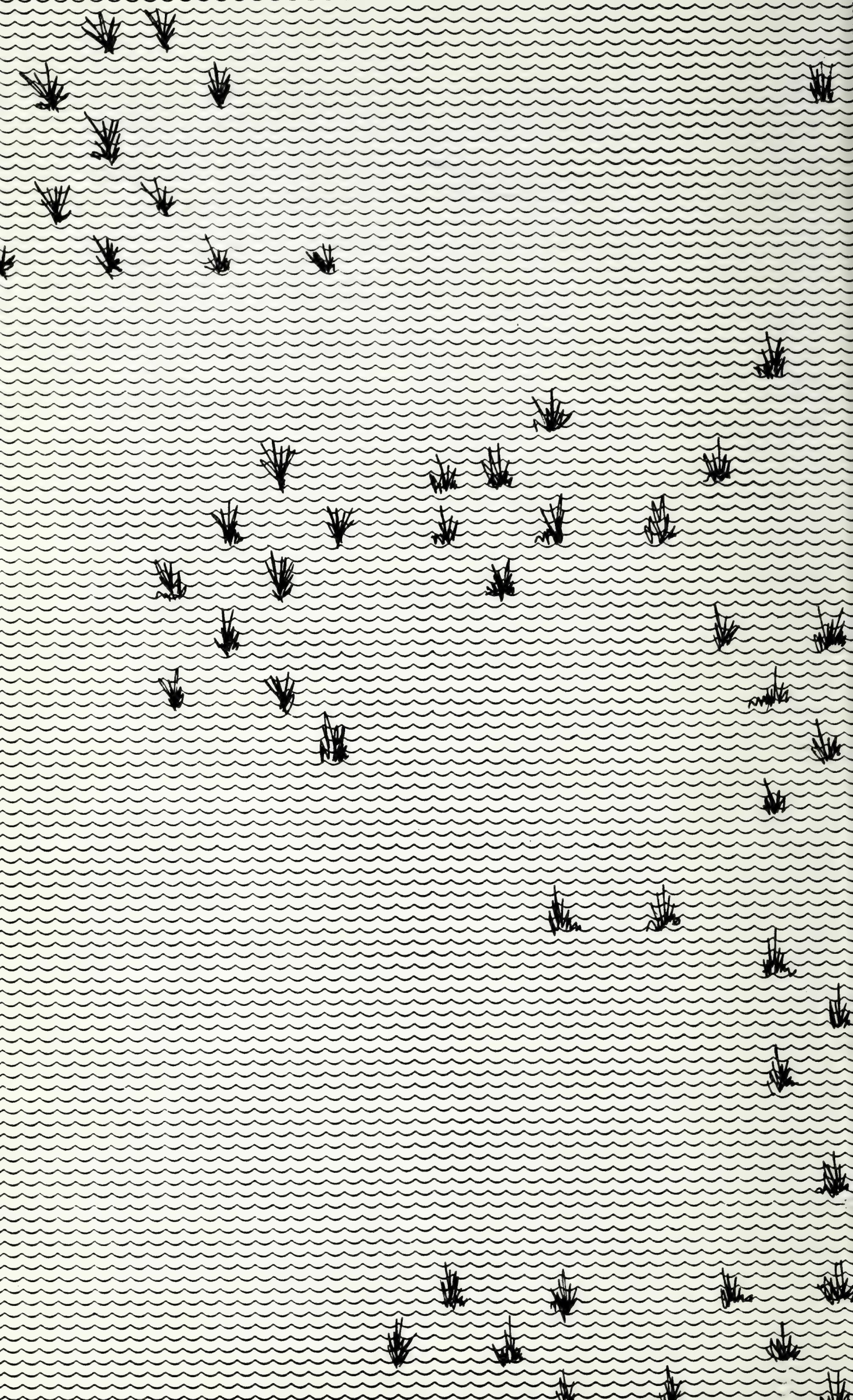

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Demographic Factors, Medical Personnel and Facilities Of Health Service Planning Regions For Louisiana

A Statistical Compendium for Planners

Evans W. Curry
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LOUISIANA STATE UNIVERSITY
AND AGRICULTURAL AND MECHANICAL COLLEGE

AGRICULTURAL EXPERIMENT STATION
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IN COOPERATION WITH
LOUISIANA REGIONAL MEDICAL PROGRAM
J. A. SABATIER, JR., M.D., DIRECTOR

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Foreword

The Louisiana Regional Medical Program has been supporting the Departments of Sociology and Rural Sociology at Louisiana State University in an investigation of the availability of medical care resources and the relationship of the availability of health manpower and facilities to health care delivery. The first report (LSU Agricultural Experiment Station Bulletin No. 637, August 1969, "The Availability and Distribution of Health Personnel in Louisiana") presented the distribution and availability of selected health manpower within the state. The second report (LSU Agricultural Experiment Station Bulletin No. 650, January 1971, "Health Service Planning Regions for Louisiana") analyzed the adequacy of selected health care resources, suggested medical service subregions, and provided data to assist health care planning.

This third and final report presents selected demograpic and socioeconomic factors as well as health care resources information that might assist delivery system planning. It is hoped that health planners will find such regional statistics meaningful.

J. A. Sabatier, Jr., M.D.
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Demographic Factors, Medical Personnel and Facilities of Health Service Planning Regions For Louisiana*

A Statistical Compendium for Planners

Evans W. Curry, Alvin L. Bertrand, Mary Z. Ferrell
and Virginia P. Steelman**

Introduction

Recent years have witnessed growing concern on the part of many groups and individuals over the rising cost of medical care. In addition, it has become increasingly clear that such care is not equally accessible to all. These facts have served as inspiration for research programs designed to improve health delivery systems throughout the nation. The results of such a study are presented in this bulletin.

This is the third and last report in a series designed to provide information which might be helpful in improving the quality and availability of health care in Louisiana. All three reports are addressed to the general theme that the availability of key personnel and specialized facilities in carefully worked out centralized localities will improve health care delivery. These reports stem from research supported cooperatively by the Louisiana Agricultural Experiment Station and the Louisiana Regional Medical Program.

The first bulletin dealt with the distribution and availability of medical and paramedical personnel within the state and demonstrated the relative unevenness in location of such personnel.[1] The second report included the results of work done to delineate meaningful medical service regions and provided a basis for planning a total health care delivery system.[2] This final publication has as its purpose the provision of a medical sociodemographic profile of each of the regions delineated so that planners and policy makers will have a readily available data base for making decisions.

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[1] Carl F. Baty, Alvin L. Bertrand, Virginia P. Steelman, *The Availability and Distribution of Health Personnel in Louisiana.* Baton Rouge, Louisiana: Agricultural Experiment Station, Bulletin 637, 1969.

The information in this report was obtained in a number of ways. First, data on medical and paramedical personnel and on the total population were collected from secondary sources and computations of rates of the former to the latter were made. These data were presented in a preliminary form in the first report mentioned. Second, a medical adequacy index, which indicated the relative potential availability of medical personnel in each parish, was developed. This index was used in the delineation of medical service regions and was incorporated into a "gravitational model." The steps in the computation of this index and the relative standing of the various parishes were presented in the second report.

The final procedural step led to the findings reported here. It involved the collation of demographic and medical personnel data by parish and region for the state, and an analysis of the relative standing and needs of each region. National rates per 1,000 population were established for all medical and paramedical manpower and hospital beds. These figures were employed as "norms" in assessing the status of manpower and facilities within the parishes and regions.

With regards to the decision to use national rates per 1,000 population for comparative purposes, it must be noted that national rates do not represent a standard about which there is a consensus. In fact, there is not an existing set of standards for medical and paramedical manpower and facilities which is accepted generally by health planning agencies and professional medical organizations. Standards employed by different groups tend to vary widely; some are much lower than national rates per 1,000 population. In view of this lack of consensus the writers chose to use national rates (an index of resources nationally) for comparative purposes in the analysis of medical and paramedical manpower and facilities within regions. They do not cite these rates as anything but a standard of measurement.

The organization of the materials which follow is straight-forward and simple. Each section of the report is devoted to one of the regions delineated previously. The medical personnel and demographic characteristics[3] of the region are described, and the striking features of the region from the standpoint of health care delivery are identified, insofar as possible. Data for the parishes which comprise the region are also given.

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[2] Carl F. Baty, Alvin L. Bertrand, Virginia P. Steelman, Evans W. Curry, *Health Service Planning Regions for Louisiana*. Baton Rouge, Louisiana: Agricultural Experiment Station, Bulletin 650, 1971.

[3] In addition to the age-dependency tables included in each regional analysis, the Appendix includes a table showing the proportion of population within each parish in the pediatric (0-14) and geriatric (65+) age groups.

Characteristics of the Alexandria Health Service Planning Region

The Alexandria Health Service Planning Region is made up of seven parishes—Allen, Avoyelles, Grant, LaSalle, Vernon, Rapides, and Winn. Altogether these parishes included a population of 273,752 persons in 1970.

It can be seen in Table 1 that the region is predominantly rural, since 56.7 percent of its population live outside of urban centers. Two of the parishes in the region, Grant and LaSalle, are completely rural and in a third, Avoyelles, almost three-fourths of the people live in rural places as defined by the U.S. Census Bureau. Allen and Winn parishes are also predominately rural, 64.9 and 56.4 percent respectively. Vernon Parish is the most urban of the seven parishes (60 percent). However, the residence picture in this parish is somewhat distorted by the presence of Fort Polk. Slightly over half of the population of Rapides Parish (52 percent) is urban. This population being concentrated primarily in Alexandria accounts for its strategic position as the hub of the region.

TABLE 1.—Population of the Alexandria Health Service Planning Region by Residence, 1970*

Parish	Urban		Rural		Total
	Total	Percent	Total	Percent	
Allen	7,301	35.1	13,493	64.9	20,794
Avoyelles	9,914	26.3	27,837	73.7	37,751
Grant	0	0	13,671	100.0	13,671
LaSalle	0	0	13,295	100.0	13,295
Rapides	61,584	52.2	56,494	47.8	118,078
Vernon	32,483	60.4	21,311	39.6	53,794
Winn	7,142	43.6	9,227	56.4	16,369
Total	118,424	43.3	155,328	56.7	273,752

*Source: Advance Report, U.S. Census, 1970, PC (V2)–20.

Table 2 was prepared to show the age-dependency ratio of the region and of its component parishes. This ratio relates the number of persons less than 20 years of age and those 65 years of age and over to individuals of 20 to 65 years of age.[4] Such ratios tell a great deal about potential health care needs, in that such needs are related to age to a rather reliable extent; i.e., the very young and the very old require large amounts of different types of medical services. Scrutiny

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[4] The ages used in computing dependency ratios represent an arbitrary decision. However, the authors based their decision on the facts that most youngsters remain dependent until after high school and most older persons retire around age 65. See: Bogue, Donald J., *Principles of Demography*, John Wiley and Sons, Inc., New York, 1969, p. 155.

TABLE 2.—**Age-Dependency Ratios of Parishes in the Alexandria Health Service Planning Region, 1970**

Parish	Age-dependency ratio*
Allen	113
Avoyelles	117
Grant	111
LaSalle	100
Rapides	101
Vernon	74
Winn	106
Regional ratio	99

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

of Table 2 reveals the following facts.

Allen, Avoyelles and Grant parishes have especially high age-dependency ratios. It can be seen that there is more than one person in the dependent ages for every person in the so-called productive ages. In LaSalle and Rapides, the numbers in the dependent ages and productive ages are about even, while Winn might be termed moderately high. Again the picture in Vernon Parish, which shows a low dependency ratio of 74, is distorted by the presence of Fort Polk.

The dependency ratio for the total Alexandria Region is 99. There are thus fewer young and old in the Alexandria Region than there are persons in ages from 20 to 65 years of age. Health programs should be planned accordingly.

The distribution of medical and paramedical manpower and of hospital and nursing home beds in the Alexandria Region is shown in Table 3. A striking fact is that only three medical or surgical specialists in the region are located outside of Rapides Parish. It is clear that many individuals must travel to Alexandria from rather distant places to obtain such services.

There is a more even distribution of physicians, dentists and nurses in the region, but the concentrations are still in Rapides Parish. These concentrations are even more obvious in the case of paramedical practitioners and again indicate the vital role of a medical regional service center in providing health care for a large area.

There is, as can be seen in Table 3, a better distribution of hospital beds. This distribution is accounted for in part by the presence of Fort Polk (a large military base) in Vernon Parish and a small hospital in Avoyelles Parish.

Nursing homes, apparently, are becoming an increasing part of the health care picture in the United States. It was for this reason that an

TABLE 3.—Distribution of Medical and Paramedical Manpower and of Hospital and Nursing Home Beds, Alexandria Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Allen	10	1	0	7	16	16	2	0	2	0	2	81	48
Avoyelles	16	0	0	10	32	25	5	0	3	2	4	54	487
Grant	2	0	0	2	2	20	0	0	3	2	0	0	0
LaSalle	7	0	0	5	8	12	2	0	1	1	1	18	90
Rapides	140	20	44	47	386	286	45	4	39	17	7	98	1,012
Vernon	7	0	0	6	30	36	10	0	2	4	2	82	127
Winn	8	1	1	5	14	20	2	0	2	0	2	69	171
Total	190	22	45	82	488	415	66	4	52	26	18	402	1,935

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).

[2] *Official List Dentists*, Louisiana State Board of Dentistry (1965-67).

[3] Official List of the Louisiana State Board of Nurse Examiners (1967).

[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).

[5] Board of Registry, American Society of Clinical Pathologists (1967).

[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).

[7] The American Registry of Radiologic Technologists (1968).

[8] Roster, Louisiana Dietetic Association (1968).

[9] Roster, Louisiana State Association of Optometrists (1968).

[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities*. Louisiana State Department of Hospitals (1968).

[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

effort was made to show the availability of such facilities in each of the parishes. The number of such beds in Rapides Parish stands out. However, while there are more than twice as many nursing home beds in this parish as there are in Avoyelles, which has the second highest total for a parish in the region, the ratios per 1,000 population are not appreciably different. One parish, Grant, has no beds, and two parishes, LaSalle and Vernon, have approximately one-tenth the number of beds as Rapides and Allen Parish has less than one-twentieth as many beds.

Descriptive information has more utility when meaningful comparisons can be made. It was in cognizance of this fact that an attempt was made to provide some common base for comparing the adequacy of medical personnel and hospital and nursing home beds in the Alexandria Region. The best such indicator that could be determined was a total population ratio. Table 4 indicates the rates per 1,000 persons characteristic of the various medical personnel and health facilities studied. It can be seen that in some instances—licensed practical nurses, medical technologists, dietitians, and optometrists—regional rates equal or exceed national averages. However, rates for all other classes of medical personnel, as well as hospital beds, are well below national norms. This picture is such as to cause some concern on the part of the planners for health and medical care in the region.

It was felt that some indication of the economic base in each region would be meaningful in terms of planning over-all state programs related to health care delivery. After considerable consultation and review of possible summary indicators of economic potential, it was decided that per capita income was about as good an indicator of ability to afford and support health care as could be found. Regional totals for personal income and per capita income are shown in Table 5. These data indicate that the Alexandria Health Service Planning Region is a relatively disadvantaged one. It ranks fifth among the seven state regions in per capita income. The income available annually to each individual in the region as of 1968 was well below the state per capita average computed on the same base (see explanatory note, Table 5).

The final table which has relevance for this discussion of the Alexandria Health Service Planning Region is Table 6. Here the medical adequacy index of the various parishes in the region is shown. This index, as mentioned previously, is a computation based on the sum of the averages or means of all personnel and hospital beds in the state related to a population base. The state average was taken as a base of 100 and parish and regional indices were worked out accordingly. Even a cursory inspection of Table 6 shows that the Alexandria Region is relatively inadequate in medical personnel, even within the state. In fact, if it were not for Rapides Parish, the region would present a rather desperate picture. As it is, there is an indication of considerable unmet need.

TABLE 4.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Alexandria Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Allen	.48	.05	0	.34	.77	.77	.10	0	.10	0	.10	3.90	2.31
Avoyelles	.42	0	0	.26	.85	.66	.13	0	.08	.05	.11	1.43	7.19
Grant	.15	0	0	.15	.15	1.46	0	0	.22	.15	0	0	0
LaSalle	.53	0	0	.38	.60	.90	.15	0	.08	.08	.08	1.35	6.76
Rapides	1.19	.17	.37	.40	3.27	2.42	.38	.03	.33	.14	.06	5.06	8.57
Vernon	.13	0	0	.11	.56	.67	.19	0	.04	.07	.04	1.52	2.36
Winn	.49	.06	.06	.31	.86	1.22	.12	0	.12	0	.12	4.22	10.45
Regional rate	.69	.08	.16	.30	1.78	1.52	.24	.01	.19	.09	.07	1.47	7.07
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Table 1 and Table 3.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 5.—Total Personal Income in the Parishes of the Alexandria Health Service Planning Region

Parish	Total personal income	Per capita income
Allen	43,394,000	1,895
Avoyelles	59,572,000	1,470
Grant	21,011,000	1,565
LaSalle	24,569,000	1,575
Rapides	280,649,000	2,278
Vernon	219,583,000	3,701
Winn	33,461,000	1,990
Regional total	682,239,000	2,492*

*This figure based on total personal income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 6.—Medical Adequacy Indices of Parishes in the Alexandria Health Service Planning Region

Parish	Medical adequacy index
Allen	78
Avoyelles	68
Grant	49
LaSalle	78
Rapides	210
Vernon	48
Winn	90
Mean	89

Computed from data in Table 4.

Characteristics of the Baton Rouge Health Service Planning Region

The population of the Baton Rouge Health Service Planning Region is considerably larger than the Alexandria Region. It includes nine parishes—Ascension, East Baton Rouge, East Feliciana, Iberville, Livingston, Pointe Coupee, St. Helena, West Baton Rouge and West Feliciana. Altogether, these parishes included almost one-half million people within their borders in 1970.

In contrast to the Alexandria Region, the Baton Rouge Region shows up as predominantly urban (62.5 percent). However, this is somewhat misleading, as all of the parishes in the region except East Baton Rouge are predominantly rural, and two of the parishes (St. Helena and West Feliciana) have no population center large enough to be classified as urban by the U.S. Bureau of the Census. In Livingston and Pointe Coupee parishes over 80 percent of the population is rural.

The population of these four parishes is in sharp contrast to the population of East Baton Rouge Parish, where almost nine of 10 persons reside in an urban place. The above information is shown in tabular form in Table 7. It serves to highlight the broad population base for health care delivery in the Baton Rouge Health Service Planning Region.

The age-dependency ratio in the Baton Rouge Region is very close to one person in the dependent ages to one person in the productive ages. This is the lowest ratio among all the regions, including the New Orleans Region. Such a ratio indicates there is more ability to support health care in that there are relatively fewer persons of the ages where health needs and costs are most often the responsibility of others (Table 8).

TABLE 7.—Population of the Baton Rouge Health Service Planning Region, by Residence, 1970

	Urban		Rural		
Parish	Total	Percent	Total	Percent	Total
Ascension	11,879	32.0	25,207	68.0	37,086
E. Baton Rouge	247,869	86.9	37,298	13.1	285,167
E. Feliciana	4,697	26.6	12,960	73.4	17,657
Iberville	10,245	33.3	20,501	66.7	30,746
Livingston	6,752	18.5	29,759	81.5	36,511
Pointe Coupee	3,945	17.9	18,057	82.1	22,002
St. Helena	0	0	9,937	100.0	9,937
W. Baton Rouge	6,558	38.9	10,306	61.1	16,864
W. Feliciana	0	0	11,376	100.0	11,376
Total	291,945	62.5	175,401	37.5	467,346

Source: Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 8.—Age-Dependency Ratios of Parishes in the Baton Rouge Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Ascension	113
East Baton Rouge	92
East Feliciana	105
Iberville	123
Livingston	104
Pointe Coupee	126
St. Helena	132
West Baton Rouge	117
West Feliciana	50
Regional ratio	98

*Ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

It is not unexpected that a region with as large a population base as the Baton Rouge Region would have a considerable number of medical and paramedical practitioners. This is true for the region as a whole, as can be seen in Table 9, but the concentration in East Baton Rouge Parish is readily apparent. Of the 435 physicians living in the region in 1969, 369 gave an address in this parish. In addition, all of the medical specialists and all but six of the surgical specialists in the region reside in the Baton Rouge area. Dentists and nurses are slightly more dispersed, but the distribution pattern is the same. Hospital and nursing home beds also are overwhelmingly in the core parish of the region.

The above pattern again serves to emphasize the key role of a centralized place in the delivery of health care. It also clearly demonstrates the rationale for the regional approach to health care planning. The location of specialized personnel and equipment in a centrally located place enhances the opportunity to provide maximum care.

Those persons who live in the Baton Rouge Region may find reassurance in the number of doctors, dentists, nurses, etc., available to them. However, an inspection of Table 10 will dispel any feelings of complacency which might develop. Baton Rouge is not up to national patterns in most of the ratios derived. The challenge which still exists is apparent in this type of statistic.

There is an encouraging fact insofar as health delivery in the Baton Rouge Region is concerned. This is the relatively high level of per capita income. It can be seen in Table 11 that in two of the parishes of the region, Ascension and East Baton Rouge, per capita income was over $3,000 annually. In two other parishes, Iberville and West Feliciana, per capita income was well over $2,000. The three parishes with the lowest per capita income in 1968 were East Feliciana, Pointe Coupee and St. Helena. Contemplation of the above leads to the conclusion that financial resources of the Baton Rouge Region are relatively great, and therefore have implications for health care delivery.

The preceding discussion has provided hints as to the adequacy of the Baton Rouge Region in the matter of health care potential. Table 12 was prepared to show the medical adequacy indices computed for parishes within the region. It can be seen that only two parishes exceed state averages for medical and paramedical personnel and hospital beds when reduced to one index—East Baton Rouge and Iberville. Three parishes, Pointe Coupee, St. Helena and West Feliciana, do not even reach one-half of the state averages. They account for the rather low mean medical adequacy index of the total region—76.

In summary, the Baton Rouge Health Service Planning Region has a large population base and an availability of personnel and services which is somewhat low. However, resources appear to be adequate. With proper planning, optimum health care delivery does not represent an unattainable goal for the future.

TABLE 9.—Distribution of Medical and Paramedical Manpower and of Hospital and Nursing Home Beds, Baton Rouge Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Ascension	12	0	2	10	18	19	3	0	7	1	3	99	112
E. Baton Rouge	369	76	119	134	775	499	102	4	57	52	19	1,275	1,004
E. Feliciana	19	0	1	1	43	22	1	0	1	1	0	20	0
Iberville	14	0	1	10	42	40	1	2	4	2	1	65	77
Livingston	5	0	1	6	36	39	4	0	7	2	2	55	122
Pointe Coupee	7	0	0	4	14	16	2	0	0	0	0	23	38
St. Helena	2	0	1	0	7	2	0	0	2	1	0	35	0
W. Baton Rouge	4	0	0	3	9	17	1	0	2	0	0	0	0
W. Feliciana	3	0	0	2	4	11	0	0	0	0	0	0	0
Total	435	76	125	170	948	655	124	6	80	59	25	1,572	1,353

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).

[2] *Official List Dentists*, Louisiana State Board of Dentistry (1965-67).

[3] Official List of the Louisiana State Board of Nurse Examiners (1967).

[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).

[5] Board of Registry, American Society of Clinical Pathologists (1967).

[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).

[7] The American Registry of Radiologic Technologists (1968).

[8] Roster, Louisiana Dietetic Association (1968).

[9] Roster, Louisiana State Association of Optometrists (1968).

[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities*. Louisiana State Department of Hospitals (1968).

[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

TABLE 10.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Baton Rouge Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Ascension	.32	0	.05	.27	.49	.51	.08	0	.19	.03	.08	2.67	3.02
E. Baton Rouge	1.29	.27	.42	.47	2.72	1.75	.39	.01	.20	.18	.07	4.47	3.52
E. Feliciana	1.08	0	.06	.06	2.44	1.25	.06	0	.06	.06	0	1.13	0
Iberville	.46	0	.03	.33	1.37	1.30	.03	.07	.13	.07	.03	2.11	2.50
Livingston	.14	0	.03	.16	.99	1.07	.11	0	.19	.05	.05	1.51	3.34
Pointe Coupee	.32	0	0	.18	.64	.73	.09	0	0	0	0	1.05	1.73
St. Helena	.20	0	.10	0	.70	.20	0	0	.20	.10	0	3.52	0
W. Baton Rouge	.24	0	0	.18	.53	1.01	.06	0	.12	0	0	0	0
W. Feliciana	.26	0	0	.18	.35	.09	0	0	0	0	0	0	0
Regional rate	.93	.16	.27	.36	2.03	1.40	.27	.01	.17	.13	.05	3.36	2.90
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 7 and 9.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 11.—Total Personal Income in the Parishes of the Baton Rouge Health Service Planning Region

Parish	Total personal income	Per capita income
Ascension	96,852,000	3,035
East Baton Rouge	941,337,000	3,173
East Feliciana	26,108,000	1,318
Iberville	76,927,000	2,567
Livingston	*	*
Pointe Coupee	31,565,000	1,405
St. Helena	13,661,000	1,494
West Baton Rouge	27,490,000	1,830
West Feliciana	26,477,000	2,226
Regional total	1,240,417,000	2,654**

*Data not available.

**This figure based on total personal income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 12.—Medical Adequacy Indices of Parishes in the Baton Rouge Health Service Planning Region

Parish	Medical adequacy index
Ascension	66
East Baton Rouge	202
East Feliciana	79
Iberville	102
Livingston	62
Pointe Coupee	38
St. Helena	48
West Baton Rouge	77
West Feliciana	20
Mean	76

Computed from data in Table 10.

Characteristics of the Lafayette Health Service Planning Region

The Lafayette Health Service Planning Region is located between the Baton Rouge and Lake Charles regions in South Louisiana. It encompasses one less parish than the Baton Rouge Region and four more than the Lake Charles Region. The eight parishes in the region are Acadia, Evangeline, Iberia, Lafayette, St. Landry, St. Martin, St. Mary, and Vermilion. All of these parishes are in the heart of so-called French Louisiana. This has significance in the sense that certain aspects of the culture, such as food habits and attitudes toward health matters, affect the delivery of health care. It is not within the scope of this report to elaborate on such factors, but they must be considered in any over-all scheme to improve health care delivery.

The population of the eight parishes in the Lafayette Region numbered about 468,000 persons in 1970. It may surprise some persons to learn that this region includes as many people as the Baton Rouge Region and more than the Shreveport Region. However, it must be remembered that this is one of the most populous areas in the state.

The residence characteristics of the parishes in the Lafayette Region do not vary as widely as in the other regions. One can see from Table 13 that each parish has some balance between rural and urban residents, with one-half the parishes having more urban than rural dwellers and the other half just the reverse. As one might expect, Lafayette Parish, including the City of Lafayette, is the most urban parish in the region. Yet only seven out of 10 persons in this parish live in towns or cities. St. Martin is the most rural parish, but even here close to two-fifths of the people live in urban places.

TABLE 13.—Population of the Lafayette Health Service Planning Region, by Residence, 1970

	Urban		Rural		
Parish	Total	Percent	Total	Percent	Total
Acadia	29,591	56.8	22,518	43.2	52,109
Evangeline	12,967	40.6	18,965	59.4	31,932
Iberia	36,469	63.5	20,928	36.5	57,397
Lafayette	78,544	71.6	31,172	28.4	109,716
St. Landry	31,399	39.1	48,965	60.9	80,364
St. Martin	12,095	37.3	20,358	62.7	32,453
St. Mary	39,609	65.2	21,143	34.8	60,752
Vermilion	16,536	38.4	26,535	61.6	43,071
Total	257,210	55.0	210,584	45.0	467,794

Source: Advance Report, U.S. Census, 1970, PC (V2)–20.

Table 14 was developed to show the age-dependency ratios in the Lafayette Region. One fact which clearly stands out is the high ratio of persons in the dependent ages to persons in the productive ages. Every parish in the region has a ratio of over 100 and the ratio for the entire region is 110. One can understand this phenomenon in terms of the rurality of the region and in terms of the religious culture. The region is overwhelmingly Roman Catholic and, until recently, church bans on artificial means of birth control were widely adhered to. The latter has relevance for this report in that planning in this region must allow for excessive numbers of younger people, at least for the next several years.

The Lafayette Region is not characterized by a concentration of medical and paramedical persons in one central place. It is true that the City of Lafayette does inflate the numbers of the above to a point above that of other parishes in the region, but the predominance is

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TABLE 14.—Age-Dependency Ratios of Parishes in the Lafayette Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Acadia	111
Evangeline	111
Iberia	114
Lafayette	102
St. Landry	118
St. Martin	109
St. Mary	112
Vermilion	108
Regional ratio	110

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2) – 20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

not as pronounced as in the Baton Rouge Region. Interestingly, St. Landry Parish has more licensed practical nurses than Lafayette Parish, probably accounted for by the presence of a training center for LPN's in the City of Opelousas. The number of physicians, dentists, etc. is shown for each parish in the region in Table 15.

It is anticipated that parishes with relatively large numbers of people living in rural areas and relatively large numbers of children will show up as disadvantaged when national rates are used as norms. The Lafayette Region is no exception. What strikes the investigator is the large number of instances in which regional rates are less than half of national rates. For example, nationally there are 1.63 physicians per 1,000 persons, but in the Lafayette Region the rate is only .75 per 1,000; nationally the rate for medical specialists is .35 per 1,000 persons, but in this region it is only .10; in the nation there are 3.29 registered nurses per 1,000 persons, but in this region there are only 1.26 registered nurses per 1,000 persons. Other such disparities can be determined by inspection of Table 16.

Per capita income for the various parishes in the Lafayette Region is shown in Table 17. One can readily see, by making comparisons with other regions, that this region is not affluent. No parish in the region registers a per capita income of as much as $3,000, and the lowest per capita income in any parish is around $1,500. Table 17 seems to indicate that anything more than an intermediate level of health care delivery calls for outside financial assistance.

The medical adequacy indices which appear in Table 18 reflect a more adequate status for the Lafayette Region than is true for any other region of the state. This is a most interesting pattern which must be related to the balance in number of medical personnel and in medical facilities within the region. In only one parish is there a glaring

TABLE 15.—Distribution of Medical and Paramedical Manpower and Hospital and Nursing Home Beds, Lafayette Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Acadia	33	5	7	11	47	65	4	1	9	1	4	162	252
Evangeline	15	0	0	7	35	52	3	0	15	0	3	164	100
Iberia	40	4	9	20	64	72	10	2	10	1	3	166	187
Lafayette	136	23	46	37	237	175	53	3	30	19	6	711	313
St. Landry	57	7	17	27	76	189	12	2	7	1	7	223	231
St. Martin	8	0	1	7	9	20	2	0	4	0	1	40	0
St. Mary	35	4	8	17	80	33	5	2	7	3	5	150	124
Vermilion	26	2	5	12	40	54	13	3	6	1	1	165	150
Total	350	45	93	138	588	660	102	13	88	26	30	1,781	1,357

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).
[2] *Official List Dentists*, Louisiana State Board of Dentistry (1965-67).
[3] Official List of the Louisiana State Board of Nurse Examiners (1967).
[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).
[5] Board of Registry, American Society of Clinical Pathologists (1967).
[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).
[7] The American Registry of Radiologic Technologists (1968).
[8] Roster, Louisiana Dietetic Association (1968).
[9] Roster, Louisiana State Association of Optometrists (1968).
[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities*. Louisiana State Department of Hospitals (1968).
[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

TABLE 16.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Lafayette Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Acadia	.63	.10	.13	.21	.90	1.25	.08	.02	.17	.02	.08	3.11	4.84
Evangeline	.47	0	0	.22	1.10	1.63	.09	0	.47	0	.09	5.14	3.13
Iberia	.70	.07	.16	.35	1.12	1.25	.17	.03	.17	.02	.05	2.89	3.26
Lafayette	1.24	.21	.42	.34	2.16	1.60	.48	.03	.27	.17	.05	6.48	2.85
St. Landry	.71	.09	.21	.34	.96	2.35	.15	.02	.09	.02	.09	2.77	2.87
St. Martin	.25	0	.03	.22	.28	.62	.06	0	.12	0	.03	1.23	0
St. Mary	.58	.07	.13	.28	1.32	.54	.08	.03	.12	.05	.08	2.47	2.04
Vermilion	.60	.05	.12	.28	.93	1.25	.30	.07	.14	.02	.02	3.83	3.48
Regional rate	.75	.10	.20	.30	1.26	1.41	.22	.03	.19	.06	.06	3.81	2.90
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 13 and 15.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 17.—Total Personal Income in the Parishes of the Lafayette Health Service Planning Region

Parish	Total personal income	Per capita income
Acadia	98,589,000	1,892
Evangeline	50,445,000	1,487
Iberia	133,275,000	2,336
Lafayette	275,393,000	2,573
St. Landry	132,019,999	1,554
St. Martin	39,456,000	1,265
St. Mary	180,979,000	2,818
Vermilion	85,897,000	2,079
Regional total	996,053,000	2,129*

*This figure based on total income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 18.—Medical Adequacy Indices of Parishes in the Lafayette Health Service Planning Region

Parish	Medical adequacy index
Acadia	94
Evangeline	98
Iberia	111
Lafayette	203
St. Landry	116
St. Martin	43
St. Mary	96
Vermilion	121
Mean	110

Computed from data in Table 16.

disparity in medical adequacy as measured by state means. From this picture one might surmise that the region is quite well accommodated for health care delivery. However, one must remember that state means are not adequate when measured by national norms.

An overview of the characteristics of the Lafayette Region might be presented in this manner. The region includes a relatively large number of people, with a more even distribution of health personnel and facilities than most other regions in the state. Yet the large number of persons in the dependent ages and the average levels of income suggest certain problems and needs which demand special attention from planners.

Characteristics of the Lake Charles Health Service Planning Region

The Lake Charles Region is located in the Southwestern part of the state. It is made up of four parishes with Calcasieu Parish serving as the core parish. The other parishes are Beauregard, Cameron, and Jefferson Davis. This region is only about half as large, population-wise, as the Baton Rouge, Lafayette, and Shreveport regions. Indeed it is the smallest of the seven health planning regions delineated. There were less than one-quarter million people in the Lake Charles Region in 1970 (see Table 19).

From the standpoint of residence, the inhabitants of the Lake Charles Region present an interesting pattern. In Beauregard Parish almost two-thirds of the people maintain a rural residence and have the health problems and needs characteristic of such a population. In contrast, two of the remaining three parishes have a predominance of urban residents (Calcasieu, 75 percent; Jefferson Davis, 63 percent). The remaining parish, Cameron, is 100 percent rural. Since Calcasieu Parish includes over half the total number of people in the region, it is understandable why the total region has a population that is nearly two-thirds urban.

The demographic information given above serves to place the health service problem in the Lake Charles Region in a statewide perspective. The number of people to be serviced is smaller than in the other regions and most of them live in an urban place where certain facilities can be expected to be available.

The age-dependency ratio in the Lake Charles Region is 102, as can be seen in Table 20. This is a relatively high ratio for a region with such an urban predominance. It probably can be explained by the fact that the economic base of the region tends to be agricultural. The religious factor also remains important in this South Louisiana area.

TABLE 19.—Population of the Lake Charles Health Service Planning Region, by Residence, 1970

	Urban		Rural		
Parish	Total	Percent	Total	Percent	Total
Beauregard	8,030	35.1	14,858	64.9	22,888
Calcasieu	108,713	74.8	36,702	25.2	145,415
Cameron	0	0	8,194	100.0	8,194
Jefferson Davis	18,537	62.7	11,017	37.3	29,554
Total	135,280	65.7	70,771	34.3	206,051

Source: Final Counts, U.S. Census, 1970, PC (V1)–20.

TABLE 20.—Age-Dependency Ratios of Parishes in the Lake Charles Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Beauregard	102
Calcasieu	100
Cameron	104
Jefferson Davis	112
Regional ratio	102

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2) – 20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

The Lake Charles Region is another where the medical and paramedical manpower is concentrated in the core parish. Almost all the doctors, dentists and nurses in the region are concentrated in the Lake Charles area (Table 21). Hospital and nursing home beds seem to have a slightly better distribution but the basic pattern of an urban concentration of resources persists.

The number of medical and health practitioners falls far below national norms, but does not compare too badly with other regions in the state. Table 22 includes the comparisons of individual parish and regional rates of personnel and hospital beds per each 1,000 persons. The disparities which exist can be readily observed when one compares the parish and regional rates with the national rates shown at the bottom of Table 22.

Personal income for parishes in the Lake Charles Region is shown in Table 23. Compared with the Baton Rouge and New Orleans regions, this region appears to be relatively affluent. One can speculate that factors other than money account for some of the unattended needs in the region.

In light of the relatively high income of the region, it is not surprising that its medical adequacy index is over 100. The mean of the indices for the four parishes, as shown in Table 24, is 108. This implies that more medical personnel and facilities are available in this region than for the state as a whole.

A brief review of the problem of health care delivery in the Lake Charles Region indicates the population base of the region is a relatively small one which is served fairly well in comparison with state standards of medical personnel and hospital beds. This is partially accounted for by the relatively high per capita income in the area.

TABLE 21.—Distribution of Medical and Paramedical Manpower and Hospital and Nursing Home Beds, Lake Charles Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Beauregard	5	0	0	5	27	26	3	0	2	0	4	88	116
Calcasieu	128	20	41	62	290	353	37	5	35	9	12	689	563
Cameron	3	0	0	0	7	3	1	0	4	0	0	27	0
Jefferson Davis	14	0	1	13	29	39	7	1	5	3	5	125	124
Total	150	20	42	80	353	421	48	6	46	12	21	929	803

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).

[2] *Official List Dentists,* Louisiana State Board of Dentistry (1965-67).

[3] Official List of the Louisiana State Board of Nurse Examiners (1967).

[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).

[5] Board of Registry, American Society of Clinical Pathologists (1967).

[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).

[7] The American Registry of Radiologic Technologists (1968).

[8] Roster, Louisiana Dietetic Association (1968).

[9] Roster, Louisiana State Association of Optometrists (1968).

[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities.* Louisiana State Department of Hospitals (1968).

[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

TABLE 22.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Lake Charles Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Beauregard	.22	0	0	.22	1.18	1.14	.13	0	.09	0	.17	3.84	5.07
Calcasieu	.88	.14	.28	.43	1.99	2.43	.25	.03	.24	.06	.08	4.74	3.87
Cameron	.37	0	0	0	.85	.37	.12	0	.49	0	0	3.30	0
Jefferson Davis	.47	0	.03	.44	.98	1.32	.24	.03	.17	.10	.17	4.23	4.20
Regional rate	.73	.10	.20	.39	1.71	2.04	.23	.03	.22	.05	.10	4.51	3.90
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 19 and 21.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 23.—Total Personal Income in the Parishes of the Lake Charles Health Service Planning Region

Parish	Total personal income	Per capita income
Beauregard	34,812,000	1,588
Calcasieu	434,030,000	3,134
Cameron	24,298,000	3,003
Jefferson Davis	74,390,000	2,570
Regional total	567,530,000	2,754*

*This figure based on total income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 24.—Medical Adequacy Indices of Parishes in the Lake Charles Health Service Planning Region

Parish	Medical adequacy index
Beauregard	78
Calcasieu	168
Cameron	59
Jefferson Davis	128
Mean	108

Computed from data in Table 22.

Characteristics of the Monroe Health Service Planning Region

The Monroe Health Service Planning Region includes the largest number of parishes of any region, yet it is the next to smallest in total population. Other than Ouachita, which is the core parish and had a population of 115,387 in 1970, none of the 14 parishes in the region had more than 33,800 inhabitants, the total in Lincoln Parish. Of the remaining 12 parishes, eight had total populations of less than 20,000 each. Other parishes in the region are Caldwell, Catahoula, Concordia, East Carroll, Franklin, Jackson, Morehouse, Madison, Richland, Tensas, Union, and West Carroll. These parishes are in the North-Central and Northeastern sections of the state. The population of each parish and of the region is shown in Table 25.

The Monroe Region is the most rural of all the health planning regions. Actually, it included almost 2,000 more rural dwellers than urban dwellers in 1970. This is an unusual picture for this day and time. Only three of the 14 parishes—Lincoln, Ouachita and Madison—have more than half their people living in cities. The remaining 11 parishes are more rural than urban. The latter fact, again, can be expected to have serious implications for health care delivery. In this regard, rural residence tends to compound such factors as distance, high accident rates, high birth rates, and lower levels of health care sophistication.

One would expect the age-dependency ratio in the Monroe Region to be high, and it is. See Table 26. Actually it is the highest such ratio of any of the health planning regions. The regional total ratio of 112 means that every person in the productive ages in this 14-parish area is matched by 1.12 persons in the dependent ages. Six parishes in the region have dependency ratios of over 120. One cannot contemplate such high levels of dependence without thinking of their implications for health care and practice.

Tables 27 and 28 show the distribution of medical and paramedical manpower and of hospital and nursing home beds and the rates per 1,000 persons for each of the above classes. Relative to other regions, this region and its parishes rank low in both manpower and facilities. There are some physicians present in each parish, but the number is small in terms of national patterns. Nurses and nursing home beds are also distributed across the region, although concentrations are primarily in Ouachita Parish. All other classes of personnel and facilities are sparse or absent in all but the core area of the region.

Comparisons of rates of health and medical care personnel in the Monroe Region with national rates show one interesting exception to the general rule of low rates. This is in the case of licensed practical nurses. The rate of such nurses per 1,000 persons in the Monroe Region is very close to the national rate (1.55 as compared with 1.60). This

TABLE 25.—Population of the Monroe Health Service Planning Region, by Residence, 1970

Parish	Urban		Rural		
	Total	Percent	Total	Percent	Total
Caldwell	0	0	9,354	100.0	9,354
Catahoula	2,761	23.5	9,008	76.5	11,769
Concordia	10,777	47.7	11,801	53.3	22,578
E. Carroll	6,183	48.0	6,701	52.0	12,884
Franklin	5,349	22.3	18,597	77.7	23,946
Jackson	5,072	31.8	10,891	68.2	15,963
Lincoln	21,772	64.4	12,028	35.6	33,800
Madison	9,643	64.0	5,422	36.0	15,065
Ouachita	90,567	78.5	24,820	21.5	115,387
Richland	6,849	31.5	14,925	68.5	21,774
Morehouse	14,713	45.3	17,750	54.7	32,463
Tensas	0	0	9,732	100.0	9,732
Union	3,416	18.5	15,031	81.5	18,447
W. Carroll	0	0	13,028	100.0	13,028
Total	177,102	49.7	179,088	50.3	356,190

Source: Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 26.—Age-Dependency Ratios of Parishes in the Monroe Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Caldwell	113
Catahoula	119
Concordia	117
East Carroll	146
Franklin	124
Jackson	99
Lincoln	99
Madison	142
Morehouse	122
Ouachita	101
Richland	124
Tensas	143
Union	112
West Carroll	109
Regional ratio	112

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

TABLE 27.—Distribution of Medical and Paramedical Manpower and of Hospital and Nursing Home Beds, Monroe Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Caldwell	6	1	0	3	18	29	0	0	1	0	1	61	79
Catahoula	4	0	0	2	7	12	1	0	1	0	0	0	109
Concordia	7	0	1	4	12	8	2	0	3	0	1	50	116
E. Carroll	4	0	0	3	6	4	1	0	2	1	1	0	18
Franklin	10	1	0	4	18	24	0	0	1	1	1	47	228
Jackson	10	0	0	3	19	27	0	0	2	2	1	37	253
Lincoln	25	8	7	9	68	54	6	1	4	10	1	100	220
Madison	4	0	0	2	9	4	3	0	1	0	0	23	131
Morehouse	18	0	2	6	49	63	5	0	3	3	3	102	364
Ouachita	134	20	40	39	285	281	41	5	35	10	7	612	738
Richland	13	1	0	6	23	24	3	0	1	0	1	30	182
Tensas	3	0	0	1	9	5	2	0	1	0	0	22	32
Union	6	0	1	5	13	10	4	0	1	1	0	36	170
W. Carroll	3	0	0	1	9	6	2	0	0	1	1	25	82
Total	247	31	51	88	545	551	70	6	56	29	18	1,145	2,722

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).

[2] *Official List Dentists,* Louisiana State Board of Dentistry (1965-67).

[3] Official List of the Louisiana State Board of Nurse Examiners (1967).

[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).

[5] Board of Registry, American Society of Clinical Pathologists (1967).

[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).

[7] The American Registry of Radiologic Technologists (1968).

[8] Roster, Louisiana Dietetic Association (1968).

[9] Roster, Louisiana State Association of Optometrists (1968).

[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities.* Louisiana State Department of Hospitals (1968).

[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

TABLE 28.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Monroe Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Caldwell	.64	.11	0	.32	1.92	3.10	0	0	.11	0	.11	6.52	8.44
Catahoula	.34	0	0	.17	.59	1.02	.08	0	.08	0	0	0	9.26
Concordia	.31	0	.04	.18	.53	.35	.09	0	.13	0	.04	2.21	5.14
E. Carroll	.31	0	0	.23	.47	.31	.08	0	.16	.08	.08	0	1.40
Franklin	.42	.04	0	.17	.75	1.00	0	0	.04	.04	.04	1.96	9.52
Jackson	.63	0	0	.19	1.19	1.69	0	0	.13	.13	.06	2.32	15.85
Lincoln	.74	.24	.21	.27	2.01	1.60	.18	.03	.12	.30	.03	2.96	6.51
Madison	.27	0	0	.13	.60	.27	.20	0	.07	0	0	1.53	8.69
Morehouse	.55	0	.06	.18	1.51	1.94	.15	0	.09	.09	.09	3.14	3.15
Ouachita	1.16	.17	.35	.34	2.47	2.44	.36	.04	.30	.09	.06	5.30	33.89
Richland	.60	.05	0	.28	1.06	1.10	.14	0	.05	0	.05	1.38	5.61
Tensas	.31	0	0	.10	.51	.21	0	0	.10	0	0	2.26	3.29
Union	.33	0	.05	.27	.70	.54	.22	0	.05	.05	0	1.95	9.22
W. Carroll	.23	0	0	.08	.69	.46	.15	0	0	.08	.08	1.92	6.29
Regional rate	.69	.09	.14	.25	1.53	1.55	.20	.02	.16	.08	.05	3.21	7.64
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 25 and 27.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

exception is not readily accounted for, but may be due to schools for training such personnel in the region.

The statistics that appear in Table 29 show that the people in the Monroe Region have a relatively low per capita income. No parish in the region showed an income of $3,000 per person in 1968. Clearly, the problem of health care delivery will be intensified in a region where individual income per year averages well below $3,000. Table 29 was prepared to show total personal income and per capita income by parishes for the region.

TABLE 29.—Total Personal Income in the Parishes of the Monroe Health Service Planning Region

Parish	Total personal income	Per capita income
Caldwell	15,443,000	1,618
Catahoula	21,433,000	1,714
Concordia	35,336,000	1,601
East Carroll	31,260,000	2,113
Franklin	51,516,000	2,010
Jackson	35,031,000	1,983
Lincoln	70,361,000	1,990
Madison	30,533,000	1,704
Morehouse	76,955,000	2,187
Ouachita	310,691,000	2,708
Richland	47,246,000	1,883
Tensas	19,398,000	1,687
Union	24,869,000	1,396
West Carroll	23,796,000	1,534
Regional total	793,868,000	2,229*

*This figure based on total income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

Medical adequacy relates, as indicated, to the availability of medical manpower and hospital beds. It is therefore no surprise to learn from Table 30 that the Monroe Region ranks quite poorly on such an index. There are only three parishes in the region for which the medical adequacy index exceeds the state norm. In other parishes, notably Catahoula, Concordia, Madison, Tensas, and West Carroll, the index is half or less than half of the state average. It is worthy of comment that the latter group of parishes is in the Mississippi Delta and all have high percentages of Negroes.

In summation, the Monroe Health Service Planning Region encompasses a large geographical territory which is sparsely settled by comparison with other parts of the state. As indicated by the numbers of medical personnel and facilities, this region has more problems than the other regions from a health care delivery standpoint.

TABLE 30.—Medical Adequacy Indices of Parishes in the Monroe Health Service Planning Region

Parish	Medical adequacy index
Caldwell	118
Catahoula	40
Concordia	49
East Carroll	53
Franklin	52
Jackson	81
Lincoln	153
Madison	42
Morehouse	95
Ouachita	194
Richland	70
Tensas	50
Union	63
West Carroll	50
Mean	79

Computed from data in Table 28.

Characteristics of the New Orleans Health Service Planning Region

The New Orleans Health Service Planning Region is by far the largest, in numbers of people included, of all the regions in Louisiana. In 1970 almost 1.5 million individuals were located in the region (see Table 31). Of the 13 parishes included, two (Orleans and Jefferson) have populations of over 300,000, and four (Lafourche, St. Tammany, Tangipahoa and Terrebonne) have populations of over 60,000. The remaining seven parishes in the region are Assumption, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist and Washington.

The relative urbanism of the New Orleans Region is indicated by the fact the 80 percent of its population is so classified. Three parishes in the region, as shown in Table 31, had less than 10 percent of their population classified as rural in 1970. However, seven parishes were predominantly rural—Lafourche, Plaquemines, St. Charles, Tangipahoa, St. James, St. Tammany and Assumption. With such a large urban concentration of population, the region is one for which health care delivery problems should be minimal.

The age-dependency ratios for the individual parishes in the New Orleans Region vary from a high of 132 in St. James Parish to a low of 91 in Jefferson Parish. Ratios for the individual parishes appear in Table 32. A study of this table will show the counter influences of an urban and a rural population as well as the effect of culturally derived values, such as religious beliefs. Despite the apparent diversity, the age-dependency ratio for the region is obviously inflenced by urban patterns. The ratio of 99 is low by state standards and indicates

TABLE 31.—Population of the New Orleans Health Service Planning Region, by Residence, 1970

	Urban		Rural		
Parish	Total	Percent	Total	Percent	Total
Assumption	0	0	19,654	100.0	19,654
Jefferson	323,507	95.8	14,061	4.2	337,568
Lafourche	26,753	38.8	42,188	61.2	68,941
Orleans	591,502	99.7	1,969	0.3	593,471
Plaquemines	7,135	28.3	18,090	71.7	25,225
St. Bernard	46,719	91.3	4,466	8.7	51,185
St. Charles	8,028	27.2	21,522	72.8	29,550
St. James	6,478	32.8	13,255	67.2	19,733
St. John the Baptist	12,334	51.8	11,479	48.2	23,813
St. Tammany	23,271	36.6	40,314	63.4	63,585
Tangipahoa	23,361	35.5	42,514	64.5	65,875
Terrebonne	39,999	52.6	36,050	47.4	76,049
Washington	21,974	52.3	20,013	47.7	41,987
Total	1,131,061	79.8	285,575	20.2	1,416,636

Source: Advance Report, U.S. Census, 1970, PC (V2)-20.

TABLE 32.—Age-Dependency Ratios of Parishes in the New Orleans Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Assumption	125
Jefferson	91
Lafourche	109
Orleans	94
Plaquemines	102
St. Bernard	93
St. Charles	114
St. James	132
St. John the Baptist	121
St. Tammany	106
Tangipahoa	111
Terrebonne	111
Washington	122
Regional ratio	99

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

approximately equal numbers of persons in the dependent and independent ages.

There is probably a greater accessibility to medical and health care personnel and facilities in the New Orleans Region than anywhere else in the state. Table 33 shows a relatively good distribution of medical manpower in the various parishes, especially of physicians, nurses and

TABLE 33.—Distribution of Medical and Paramedical Manpower and of Hospital and Nursing Home Beds, New Orleans Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Assumption	6	0	0	4	9	9	2	0	1	0	0	21	0
Jefferson	271	52	56	108	499	331	133	2	113	10	12	369	358
Lafourche	43	6	14	24	112	56	12	1	21	2	4	221	165
Orleans	1,850	729	626	407	2,243	1,437	331	55	165	105	58	4,304	2,185
Plaquemines	7	1	0	4	24	10	0	0	0	0	1	50	0
St. Bernard	13	3	0	4	29	41	8	0	9	1	4	44	221
St. Charles	11	1	1	7	38	15	3	0	2	0	7	29	0
St. James	8	0	0	4	20	7	4	0	2	0	0	45	40
St. John the Baptist	5	0	0	2	11	3	2	0	0	0	0	0	0
St. Tammany	64	5	13	20	116	70	8	1	20	4	5	238	341
Tangipahoa	35	3	4	17	120	72	10	2	4	5	6	245	237
Terrebonne	43	5	13	19	134	38	12	2	6	6	5	154	60
Washington	30	3	0	14	108	168	3	0	3	2	4	210	150
Total	2,386	807	733	634	3,463	2,257	528	63	346	136	99	5,930	3,757

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).

[2] *Official List Dentists*, Louisiana State Board of Dentistry (1965-67).

[3] Official List of the Louisiana State Board of Nurse Examiners (1967).

[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).

[5] Board of Registry, American Society of Clinical Pathologists (1967).

[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).

[7] The American Registry of Radiologic Technologists (1968).

[8] Roster, Louisiana Dietetic Association (1968).

[9] Roster, Louisiana State Association of Optometrists (1968).

[10] *Louisiana—1969 Plan for Construction-Modernization of Medical Facilities*. Louisiana State Department of Hospitals (1968).

[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

dentists. Nevertheless, there is still an exceptional concentration in the parishes of Orleans and Jefferson. When the personnel and facilities found in parishes near to this core area are included, the picture is one of major metropolitan concentration. For example, the number of medical and surgical specialists is quite out of proportion to other regions of the state and emphasizes the fact that much in the way of specialized equipment and facilities is located here.

The New Orleans Region is the only one in which some of the national rates relative to health manpower are not only met but exceeded. One must not be too elated, however, because rates of physicians and specialists are not high by national averages. Certain deficiencies are also apparent when it is discovered that rates for nurses and hospital beds are rather poor when compared to the U.S. as a whole. The details of rates of personnel and hospital beds per 1,000 persons appear in Table 34.

The regional picture of the New Orleans Region, insofar as per capita income is concerned, is encouraging. It can be seen in Table 35 that only two of the 13 parishes had per capita income below $2,000 in 1968. The four parishes in the New Orleans Standard Metropolitan Statistical Area (SMSA)—Jefferson, Orleans, St. Bernard and St. Tammany—are shown with an income of $3,250 per person per year. All in all, it appears that not only is health care available but can be more readily afforded here than in most other places in the state.

Table 36 was designed to show the medical adequacy indices computed for the parishes in the New Orleans Region. The index of 397 for Orleans Parish tells its own story. This core parish is the most advantageous for health care in the entire state. This is probably the best region in the state for delivery of health care. It is true that some parishes, such as Plaquemines, St. Bernard, St. James and St. John the Baptist, have low medical adequacy indices, but their proximity to Orleans Parish accounts for their poor showing.

It is easy to summarize the health care picture in the New Orleans Health Service Planning Region. It is not only the region with the largest number of people, it is the only one where certain types of care are readily available and where more people can potentially afford such care. However, two questions require further investigation. The first is the degree to which certified medical personnel are lost to teaching duties. The second is the degree to which trainees (e.g., third- and fourth-year medical students, etc.) constitute an uncounted resource in the delivery of health service. Answers to these questions would provide a more refined estimate of the potential health care available to the area. Further, these questions are particularly relevant for an area with extensive teaching programs, such as New Orleans.

TABLE 34.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, New Orleans Health Service Planning Region*

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Assumption	.31	0	0	.20	.46	.46	.10	0	.05	0	0	1.07	0
Jefferson	.80	.24	.17	.32	1.48	.98	.39	.01	.33	.03	.04	1.09	1.06
Lafourche	.62	.07	.20	.35	1.62	.81	.17	.01	.30	.03	.06	3.21	2.39
Orleans	3.12	1.23	1.05	.69	3.78	2.42	.56	.09	.28	.18	.10	7.25	3.68
Plaquemines	.28	.04	0	.16	.95	.40	0	0	0	0	.04	1.98	0
St. Bernard	.25	.06	0	.08	.57	.80	.16	0	.18	.02	.04	.86	4.32
St. Charles	.37	.03	.03	.24	1.29	.51	.10	0	.07	0	.07	.98	0
St. James	.04	0	0	.20	1.01	.35	.20	0	.10	0	0	2.28	2.03
St. John the Baptist	.21	0	0	.08	.46	.13	.08	0	0	0	0	0	0
St. Tammany	1.01	.08	.20	.31	1.82	1.10	.13	.02	.31	.06	.08	3.74	5.36
Tangipahoa	.53	.05	.06	.26	1.82	1.09	.15	.03	.06	.08	.09	3.72	3.60
Terrebonne	.57	.07	.17	.25	1.76	.50	.16	.03	.08	.08	.07	2.03	.79
Washington	.71	.07	.14	.33	2.57	4.00	.07	0	.07	.05	.10	5.00	3.57
Regional rate	1.68	.57	.52	.45	2.44	1.59	.37	.04	.24	.10	.07	4.19	2.65
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 31 and 33.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 35.—Total Personal Income in the Parishes and SMSA of the New Orleans Health Service Planning Region

Parish	Total personal income	Per capita income
New Orleans SMSA	3,458,495,000	3,250
Jefferson	*	*
Orleans	*	*
St. Bernard	*	*
St. Tammany	*	*
Assumption	34,662,000	1,758
Lafourche	128,932,000	2,056
Plaquemines	**	**
St. Charles	87,341,000	3,325
St. James	47,994,000	2,444
St. John the Baptist	**	**
Tangipahoa	113,189,000	1,688
Terrebonne	179,424,000	2,468
Washington	96,245,000	2,084
Regional total	4,146,282,000	2,927***

*Data for these parishes are agglomerated in SMSA and are not available individually.

**Data unavailable.

***This figure based on total personal income for the region in 1968 and total population for the region in 1970.

Source: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 36.—Medical Adequacy Indices of Parishes in the New Orleans Health Service Planning Region

Parish	Medical adequacy index
Assumption	68
Jefferson	129
Lafourche	116
Orleans	397
Plaquemines	40
St. Bernard	51
St. Charles	61
St. James	50
St. John the Baptist	20
St. Tammany	133
Tangipahoa	108
Terrebonne	104
Washington	140
Mean	109

Computed from data in Table 34.

Characteristics of the Shreveport Health Service Planning Region

The final health service planning region to be discussed, the Shreveport Region, is located in the Northwestern part of the state and is made up of nine parishes—Bienville, Bossier, Caddo, Claiborne, DeSoto, Natchitoches, Red River, Sabine and Webster. The number of people in this region, as of 1970, was somewhat less than was found in the Baton Rouge and Lafayette regions. Again, one core parish, Caddo, included about half of the population of the region. By contrast, Red River Parish included less than 10,000 people in its borders in 1970. The population for the remainder of the parishes is shown in Table 37.

Although two-thirds of the parishes in the Shreveport Region have predominantly rural populations, the region as a whole is only 35 percent rural. This is accounted for by the large urban population in Caddo (86 percent) and neighboring Bossier Parish (65 percent). Persons knowledgeable of this region will recognize that it tends to project a rural character, despite its large urban population. This, no doubt, stems from the presence of extensive agricultural and forest products activities in the region. It is necessary to consider the influence of the latter in planning health care delivery programs.

Age-dependency ratios in parishes in the Shreveport Region tend to run high. It can be noted in Table 38 that this ratio for the entire region is 104. A possible explanation is the rural character of the area. In this regard, it is interesting that the more urban parishes, Bossier, Caddo and Webster, have the lowest dependency ratios while the more rural parishes, like Claiborne, DeSoto, and Red River, have considerably more persons in the dependent ages relative to persons in the productive ages.

TABLE 37.—Population of the Shreveport Health Service Planning Region, by Residence, 1970

	Urban		Rural		
Parish	Total	Percent	Total	Percent	Total
Bienville	2,970	18.5	13,054	81.5	16,024
Bossier	41,845	64.9	22,674	35.1	64,519
Caddo	196,765	85.5	33,419	14.5	230,184
Claiborne	7,538	44.3	9,486	65.7	17,024
DeSoto	6,432	28.3	16,332	71.7	22,764
Natchitoches	15,974	45.4	19,245	54.6	35,219
Red River	0	0	9,226	100.0	9,226
Sabine	3,112	16.7	15,526	83.3	18,638
Webster	20,492	51.3	19,447	48.7	39,939
Total	295,128	65.1	158,409	34.9	453,537

Source: Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 38.—Age-Dependency Ratios of Parishes in the Shreveport Health Service Planning Region, 1970

Parish	Age-dependency ratio*
Bienville	115
Bossier	100
Caddo	100
Claiborne	121
DeSoto	122
Natchitoches	113
Red River	119
Sabine	114
Webster	96
Regional ratio	104

*The ratio of persons under 20 and 65 and over years of age to persons 20 through 64 years of age.

Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Note: Additional age distribution data in Appendix Table 1 show population counts and percentages for pediatric (0-14), productive (15-64), and geriatric (65+) populations within each parish.

The distribution of medical and paramedical personnel and of hospital and nursing beds in the Shreveport Region is shown in Table 39. This table indicates the familiar pattern of concentrations in the vicinity of the core parish, Caddo. Some dispersion is noted, especially among physicians, nurses, and hospital and nursing home beds, but it is not extensive.

When rates of medical personnel and of hospital beds per 1,000 population are computed, it is evident that this region, like others in the state, is well below national norms (see Table 40). Somewhat strangely, exceptions appear in the case of licensed practical nurses, medical technologists, and radiologic technologists. One explanation which can be offered for this phenomenon is the presence of training centers and specialized treatment centers located in some towns within the region, especially Natchitoches and Shreveport.

Given the urban predominance of the Shreveport Region, total personal income does not appear to be as high as one might expect. In only one parish, Webster, was per capita income over $3,000 annually. A glance at Table 41 shows that income in this parish was probably as high as anywhere in the state, some $3,507 per person per year. The only other relatively high income area in the region was the Shreveport SMSA, including the parishes of Caddo and Bossier. However, here the per capita income was not higher than $2,884. None of the other parishes in the region was characterized by per capita income of as much as $2,000 in 1968.

Medical adequacy indices for the Shreveport Region are shown in Table 42. The region compares favorably with state averages for medical personnel and hospital beds. It is clear, however, that the influence of Caddo Parish accounts for the total region index mean of

TABLE 39.—Distribution of Medical and Paramedical Manpower and of Hospital and Nursing Home Beds, Shreveport Health Service Planning Region

Parish	Total Licensed Physicians[1]	Medical Specialists[1]	Surgical Specialists[1]	Licensed Dentists[2]	Licensed Registered Nurses[3]	Licensed Practical Nurses[4]	Registered Medical Technologists[5]	Licensed Physical Therapists[6]	Registered Radiologic Technologists[7]	Registered Dietitians[8]	Licensed Optometrists[9]	Licensed Hospital Beds[10]	Licensed Nursing Home Beds[11]
Bienville	6	0	0	3	5	18	1	0	1	0	1	31	79
Bossier	23	2	5	7	71	88	10	2	22	2	3	152	196
Caddo	390	71	107	137	813	684	112	15	97	22	12	1,884	1,401
Claiborne	12	0	0	8	26	20	3	1	0	1	1	69	98
DeSoto	5	0	1	4	19	32	0	0	1	0	0	43	80
Natchitoches	15	2	1	8	49	37	9	1	5	2	2	74	205
Red River	4	0	0	1	6	8	0	0	0	1	0	53	54
Sabine	11	0	0	3	19	18	3	0	2	2	0	134	80
Webster	21	2	4	14	62	49	1	0	2	2	0	173	228
Total	487	77	118	185	1,070	954	139	19	130	32	19	2,613	2,421

[1] The Distribution of Physicians and Hospital Beds in the United States (1970).
[2] *Official List Dentists*, Louisiana State Board of Dentistry (1965-67).
[3] Official List of the Louisiana State Board of Nurse Examiners (1967).
[4] Official Roster of the Louisiana State Board of Practical Nurse Examiners (1967).
[5] Board of Registry, American Society of Clinical Pathologists (1967).
[6] Roster, Louisiana Chapter, American Physical Therapy Association (1968).
[7] The American Registry of Radiologic Technologists (1968).
[8] Roster, Louisiana Dietetic Association (1968).
[9] Roster, Louisiana State Association of Optometrists (1968).
[10] *Louisiana—1969 Plan for Contruction-Modernization of Medical Facilities*. Louisiana State Department of Hospitals (1968).
[11] Data on Licensed Nursing Home Beds provided by Robert W. Haaker (1971).

TABLE 40.—Medical and Paramedical Manpower and Hospital and Nursing Home Beds Per 1,000 Population, Shreveport Health Service Planning Region*

Parish	Total Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	Licensed Nursing Home Beds
Bienville	.37	0	0	.19	.31	1.12	.06	0	.06	0	.06	1.93	4.93
Bossier	.36	.03	.08	.11	1.10	1.36	.15	.03	.34	.03	.05	2.36	3.04
Caddo	1.69	.31	.46	.60	3.53	2.97	.49	.07	.42	.10	.05	8.18	6.09
Claiborne	.70	0	0	.47	1.53	1.17	.18	.06	0	.06	.06	4.05	5.76
DeSoto	.22	0	.04	.18	.83	1.41	0	0	.04	0	0	1.89	3.51
Natchitoches	.43	.06	.03	.23	1.39	1.05	.26	.03	.14	.06	.06	2.10	5.82
Red River	.43	0	0	.11	.65	.87	0	0	0	.11	0	5.74	5.85
Sabine	.59	0	0	.16	1.02	.97	.16	0	.11	.11	0	7.19	4.29
Webster	.53	.05	.10	.35	1.55	1.23	.03	0	.05	.05	0	4.33	5.71
Regional rate	1.07	.17	.26	.41	2.36	2.10	.31	.04	.29	.07	.04	5.76	5.34
National rate	(1.63)	(.35)	(.47)	(.57)	(3.29)	(1.60)	(.26)	(.07)	(.25)	(.10)	(.10)	(7.81)	(NA)

*Computed from data in Tables 37 and 39.

Note: National rates do not represent criteria or standards for manpower/population ratios but only a statement of present resources per 1,000 population. National rates for manpower and facilities are based on findings from the Statistical Abstract of the United States. Physicians, Medical Specialists, and Surgical Specialists are based on 1967 data and all other categories on 1968 data.

TABLE 41.—Total Personal Income in the Parishes and SMSA of the Shreveport Health Service Planning Region

Parish	Total personal income	Per capita income
Shreveport SMSA	869,809,000	2,884
Bossier	*	*
Caddo	*	*
Bienville	24,832,000	1,424
Claiborne	33,307,000	1,976
DeSoto	37,774,000	1,579
Natchitoches	65,513,000	1,771
Red River	17,401,000	1,750
Sabine	31,214,000	1,484
Webster	143,566,000	3,507
Regional total	1,223,416,000	2,697**

*Data for these parishes are agglomerated in SMSA and are not available individually.

**This figure based on total personal income for the region in 1968 and total population for the region in 1970.

Sources: Occasional Papers Number 2, Division of Research, College of Business Administration, Louisiana State University, Baton Rouge, Louisiana, February, 1971, and Advance Report, U.S. Census, 1970, PC (V2)–20.

TABLE 42.—Medical Adequacy Indices of Parishes in the Shreveport Health Service Planning Region

Parish	Medical adequacy index
Bienville	49
Bossier	91
Caddo	280
Claiborne	122
DeSoto	45
Natchitoches	99
Red River	63
Sabine	88
Webster	88
Mean	103

Computed from data in Table 40.

103. DeSoto, Bienville, and Red River parishes are the most disadvantaged parishes in this respect in the region. In each of these, the medical adequacy index is far below 100.

In summation, the Shreveport Region is a relatively large one with quite contrasting characteristics. As a whole it projects a relatively good potential for health care delivery. Yet the unevenness in distribution of health personnel and facilities leads one to suspect that the people in a rather large segment of the region do not benefit as much as they might from the available health resources.

Discussion and Conclusions

The major comparisons made in the foregoing analysis are the national rates per 1,000 population of medical and paramedical manpower and facilities. While such rates, themselves, may not be adequate as minimum rates, they must serve the researcher in lieu of specified optimum rates under given demographic and economic conditions. In 1967, the U.S. Department of Health, Education and Welfare indirectly suggested a rate of 1.72 physicians per 1,000 population as a minimum standard.[5] This is greater than the current national rate. On the other hand, a commonly employed ratio for hospital beds per 1,000 is 7.52. This is somewhat lower than the current national rate. It seems entirely probable that, in most cases, national rates per 1,000 population are lower than potential standards for evaluating adequate health care delivery.

It has been emphasized that the rurality of many of the regions and their high age-dependency ratios are major factors contributing to the inadequacy and inequity in the distribution of medical care resources in many areas of the state. Although 66.1 percent of Louisiana's 3,643,180 persons are classified as urban by the 1970 Census, this urban population resides in approximately one-third of the state's 64 parishes. Review of the Residence Tables prepared shows that the rural parishes have inadequate medical and paramedical manpower and facilities. Additionally, these tables reveal that these parishes, and their inclusive regions, have high age-dependency ratios.

Inspection of Table 43 indicates there are a minimum of manpower or facility classifications in which the regional rate equals or exceeds the national rates. The New Orleans Region's rates exceed national rates in five of 12 instances. The Alexandria and Shreveport regions, with three instances of rates equaling or exceeding national rates, rank next. The Lafayette Region has no health manpower rate which equals or exceeds national rates.

The above mentioned table clearly reveals that the picture of medical and paramedical manpower facilities, both at the parish and regional levels, is not one of imbalance or over-concentration in certain areas, but primarily one of under-concentration in all areas. This suggests that one of the challenging problems facing planners in Louisiana is the training, recruitment and maintenance of medical and paramedical personnel and the development of health care delivery facilities. The latter points to a massive planning and administrative task in the recruitment of educators and trainees and the development of facilities if Louisiana is to develop an optimum delivery of health care to her citizenry in the future. Planning of this type will proceed much more realistically if the characteristics of health service planning regions

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[5] "Health Manpower Perspective: 1967" U.S. Department of Health, Education and Welfare, Washington, D.C. pp. 9-10.

TABLE 43.—Number of Parishes Equaling or Exceeding National Rates per 1,000 Population of Medical and Paramedical Manpower and Hospital Beds, by Region, Circa 1968–1970

Region	Licensed Physicians	Medical Specialists	Surgical Specialists	Licensed Dentists	Licensed Registered Nurses	Licensed Practical Nurses	Registered Medical Technologists	Licensed Physical Therapists	Registered Radiologic Technologists	Registered Dietitians	Licensed Optometrists	Licensed Hospital Beds	No. of Parishes in Region
Alexandria	0	0	0	0	0	1*	1*	0	1	2*	3	0	7
Baton Rouge	0	0	0	0	0	1	1*	1	0	2*	0	0	9
Lafayette	0	0	0	0	0	3	2	1	2	1	0	0	8
Lake Charles	0	0	0	0	0	1*	0	0	1	1	2*	0	4
Monroe	0	0	0	0	0	5	1	0	1	2	1	0	14
New Orleans	1*	1*	1*	1	1	2	2*	1	4	1*	2	0	13
Shreveport	1	0	0	1	1	1*	2*	1	2*	3	0	1	9
Total	2	1	1	2	2	14	9	4	11	12	8	1	64

*Regional rate ≥ national rate per 1,000 population.

located in the state are kept in mind.

The goal of the writers of this bulletin has been to develop meaningful statistics for health planners. In view of this, medical, demographic and economic data have been collated into regional summaries. From these, planners should be able to evaluate populations to be served in some of their essential characteristics and distribution. Further, statistics are provided which will enable professionals to evaluate the potential of a given medical community to deliver needed health care to the population to be served.

In order to maximize the utility and flexibility of the material developed herein, data have been developed at the parish as well as the regional level. This allows for evaluation and planning at a subregional level and preserves the integrity of the material were rezoning of regions to become necessary. Finally, the data provided are ideally suited to serve as a "baseline" for an ongoing information system for health planners.

Appendix

Appendix Table 1 contains the distribution of population in Louisiana by parish and age group (pediatric, "productive," and geriatric). The age distribution within each parish is presented in terms of population count and percentage. These statistics may be used to compute additional relevant statistics, e.g., ratio of pediatric population to productive population, ratio of geriatric population to productive population, and ratio of special health need populations (pediatric and geriatic) to the productive population.

APPENDIX TABLE 1.—Distribution of Population by Parish and Age for Louisiana, 1970*

Parish	Age category	Number in population	Percent of population
	0–14	17,314	33.23
Acadia	15–64	29,939	57.45
	65 +	4,856	9.32
	0–14	6,814	32.77
Allen	15–64	11,847	56.97
	65 +	2,133	10.26
	0–14	13,395	36.12
Ascension	15–64	21,002	56.63
	65 +	2,689	7.25

(Continued)

APPENDIX TABLE 1.—(Continued)

Parish	Age	No.	Percent
Assumption	0–14	7,241	36.84
	15–64	10,792	54.91
	65 +	1,621	8.25
Avoyelles	0–14	12,236	32.41
	15–64	21,201	56.16
	65 +	4,314	11.43
Beauregard	0–14	7,087	30.96
	15–64	13,631	59.56
	65 +	2,170	9.48
Bienville	0–14	4,643	28.97
	15–64	9,041	56.42
	65 +	2,340	14.61
Bossier	0–14	22,445	34.79
	15–64	38,216	59.23
	65 +	3,857	5.98
Caddo	0–14	68,736	29.86
	15–64	137,748	59.84
	65 +	23,699	10.30
Calcasieu	0–14	44,747	30.77
	15–64	90,887	62.50
	65 +	9,781	6.73
Caldwell	0–14	2,800	29.93
	15–64	5,310	56.77
	65 +	1,244	13.30
Cameron	0–14	2,824	34.46
	15–64	4,762	58.12
	65 +	608	7.42
Catahoula	0–14	3,913	33.25
	15–64	6,629	56.32
	65 +	1,227	10.43
Claiborne	0–14	4,858	28.54
	15–64	9,275	54.48
	65 +	2,891	16.98
Concordia	0–14	7,928	35.12
	15–64	12,850	56.91
	65 +	1,800	7.97
DeSoto	0–14	6,897	30.30
	15–64	12,549	55.12
	65 +	3,318	14.58

(Continued)

APPENDIX TABLE 1.—(Continued)

Parish	Age	No.	Percent
E. Baton Rouge	0–14	87,702	30.76
	15–64	180,095	63.15
	65 +	17,370	6.09
E. Carroll	0–14	4,853	37.67
	15–64	6,627	51.43
	65 +	1,404	10.90
E. Feliciana	0–14	4,976	28.18
	15–64	10,314	58.41
	65 +	2,367	13.41
Evangeline	0–14	10,624	33.27
	15–64	18,245	57.14
	65 +	3,063	9.59
Franklin	0–14	7,959	33.24
	15–64	13,280	55.45
	65 +	2,707	11.31
Grant	0–14	4,103	30.01
	15–64	7,759	56.76
	65 +	1,809	13.23
Iberia	0–14	20,545	35.80
	15–64	32,454	56.54
	65 +	4,398	7.66
Iberville	0–14	10,801	35.13
	15–64	17,024	55.37
	65 +	2,921	9.50
Jackson	0–14	4,491	28.13
	15–64	9,509	59.57
	65 +	1,963	12.30
Jefferson	0–14	113,825	33.72
	15–64	207,118	61.36
	65 +	16,625	4.92
Jefferson Davis	0–14	10,058	34.03
	15–64	16,950	57.35
	65 +	2,546	8.62
Lafayette	0–14	36,673	33.43
	15–64	66,583	60.68
	65 +	6,460	5.89
Lafourche	0–14	24,670	35.78
	15–64	40,177	58.18
	65 +	4,094	5.94
LaSalle	0–14	3,736	28.10
	15–64	7,886	59.32
	65 +	1,673	12.58

(Continued)

APPENDIX TABLE 1.—(Continued)

Parish	Age	No.	Percent
Lincoln	0–14	7,962	23.56
	15–64	22,683	67.11
	65 +	3,155	9.33
Livingston	0–14	12,455	34.11
	15–64	21,474	58.82
	65 +	2,582	7.07
Madison	0–14	5,354	35.54
	15–64	7,767	51.55
	65 +	1,944	12.91
Morehouse	0–14	10,856	33.44
	15–64	18,068	55.66
	65 +	3,539	10.90
Natchitoches	0–14	9,757	27.70
	15–64	21,484	61.00
	65 +	3,978	11.30
Orleans	0–14	167,330	28.20
	15–64	362,975	61.16
	65 +	63,166	10.64
Ouachita	0–14	35,700	30.94
	15–64	69,639	60.35
	65 +	10,048	8.71
Plaquemines	0–14	7,677	30.43
	15–64	16,482	65.34
	65 +	1,066	4.23
Pointe Coupee	0–14	7,586	34.48
	15–64	12,219	55.54
	65 +	2,197	9.98
Rapides	0–14	38,754	32.82
	15–64	68,490	58.00
	65 +	10,838	9.18
Red River	0–14	2,853	30.92
	15–64	5,146	55.78
	65 +	1,227	13.30
Richland	0–14	7,066	32.45
	15–64	12,090	55.53
	65 +	2,618	12.02
Sabine	0–14	5,603	30.06
	15–64	10,502	56.35
	65 +	2,533	13.59
St. Bernard	0–14	17,028	33.27
	15–64	31,886	62.30
	65 +	2,271	4.43

(Continued)

APPENDIX TABLE 1.—(Continued)

Parish	Age	No.	Percent
St. Charles	0–14	11,139	37.70
	15–64	16,741	56.65
	65 +	1,670	5.65
St. Helena	0–14	3,705	37.28
	15–64	5,400	54.34
	65 +	832	8.38
St. James	0–14	7,485	37.93
	15–64	10,683	54.14
	65 +	1,565	7.93
St. John the Baptist	0–14	9,041	37.97
	15–64	13,232	55.57
	65 +	1,540	6.46
St. Landry	0–14	28,014	34.86
	15–64	45,694	56.86
	65 +	6,656	8.28
St. Martin	0–14	11,834	36.47
	15–64	19,757	60.88
	65 +	2,403	2.65
St. Mary	0–14	22,617	37.23
	15–64	34,401	56.63
	65 +	3,734	6.14
St. Tammany	0–14	21,702	34.13
	15–64	37,170	58.46
	65 +	4,753	7.41
Tangipahoa	0–14	21,174	32.14
	15–64	38,811	58.92
	65 +	5,890	8.94
Tensas	0–14	3,321	34.12
	15–64	5,137	52.79
	65 +	1,274	13.09
Terrebonne	0–14	28,452	37.41
	15–64	43,729	57.50
	65 +	3,868	5.09
Union	0–14	5,355	29.03
	15–64	10,589	57.40
	65 +	2,503	13.57
Vermilion	0–14	13,951	32.39
	15–64	24,702	57.35
	65 +	4,418	10.26
Vernon	0–14	9,959	18.51
	15–64	41,572	77.28
	65 +	2,263	4.21

(Continued)

APPENDIX TABLE 1.—(Continued)

Parish	Age	No.	Percent
Washington	0–14	15,923	37.92
	15–64	24,497	58.30
	65 +	4,337	3.78
Webster	0–14	11,244	28.15
	15–64	24,188	60.56
	65 +	4,507	11.29
W. Baton Rouge	0–14	6,117	36.27
	15–64	9,556	56.67
	65 +	1,191	7.06
West Carroll	0–14	3,683	28.27
	15–64	7,568	58.09
	65 +	1,477	13.64
W. Feliciana	0–14	2,237	19.66
	15–64	8,524	74.93
	65 +	615	5.41
Winn	0–14	4,717	28.82
	15–64	9,529	58.21
	65 +	2,123	12.97

*Source: Computed from Advance Report, U.S. Census, 1970, PC (V2)–20.

Producing Slaughter Steers With Grain Self-Fed On Pasture

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Producing Slaughter Steers With Grain Self–Fed on Pasture

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INTRODUCTION

Livestock producers in Louisiana and the Southeastern section of the United States are realizing more each year their advantages in forage production over other sections of our country. The geographical location makes possible the production of both winter and summer pastures. While summer pastures have a very high carrying capacity, the winter pastures are a real bonus in the production of beef.

Many producers are holding spring-dropped calves after weaning, grazing them on winter pastures, and selling them as yearling cattle the following spring. There is still a great deal of interest in the production of finished beef in Louisiana and the southern United States.

There has always been a discrimination against grass fattened beef because of the yellow color of the fat. Even so, profits are usually greater in a steer fattening program when pasture replaces a portion of the grain.

It is the authors' belief that finishing steers on pasture has many advantages. When fattening steers on pasture, the grain should be used as a supplement to the pasture and not as a substitute for the pasture.

This publication reports three trials conducted at the Northeast Louisiana Experiment Station, St. Joseph, Louisiana. Five rations were self-fed to grazing steers for a period of 299 days. All cattle were slaughtered and their carcasses evaluated.

PREVIOUS WORK

Research at the Northeast Louisiana Experiment Station has shown that slaughter cattle weighing 900 to 1,000 pounds can be produced by using a combination of forage crops and limited concentrates. The carcasses with a thin rind of external fat and sufficient quality to grade U.S. Good to Choice were highly acceptable to packers (Carpenter and Klett, 1969).

Carpenter et al. (1968) found that by feeding a limited amount of grain to grazing cattle over 312 days, a thin rind fat and exceptional marbling were obtained. This method was superior to two other programs on the basis of weight at slaughter, average daily gain, number of carcasses grading Choice, feed efficiency, and time required to finish the steers.

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Chapman et al. (1967) reported that the use of limited amounts of concentrates on good-quality pasture has almost always resulted in greater returns than pasture alone. The use of a limited amount of concentrate feed will result in more gain, higher dressing percent, quicker inventory turnover, and better packer-buyer acceptance of the cattle. They also reported that a full-feed of concentrate ration should not be fed to calves on pasture to produce slaughter steers. Research indicated that the economical level of supplemental feed to use on pasture would range from 0.5 to 1% of the body weight of the cattle (Chapman et al., 1967).

Chapman, Haines, and Kidder (1964) stated that the feeding of 6 pounds of a mixed feed having a crude protein content of 10 to 12% usually produced approximately 0.67 pound more gain than pasture alone.

Wise, Barrick, and Blumer (1965) self-fed a mixture of corn with 10% animal fat and used soybean meal, clover, and extra nitrogen added on forage, to determine the need for supplemental protein of steers grazing grass pastures. These investigators found that gains were not significantly changed by adding protein in the feed as soybean meal, in the forage as clover, or in the form of extra nitrogen added to growing forage. They did find, however, that the addition of soybean meal increased the daily feed intake by 2 to 3 pounds per head, resulting in more costly gains for this group.

Suman and Woods (1966) at the South Carolina Station compared yearling steers grazing Coastal bermudagrass with and without supplemental feeding. The supplements used were cottonseed meal, Coastal bermudagrass pellets, and ground shelled corn. Coastal bermudagrass gave beef gains of approximately 610 pounds per acre when fertilized with 200 pounds of nitrogen. Small additional gains were made with the protein supplements, but with ground shelled corn fed at 1% of the body weight, seasonal gains were over 1,300 pounds per acre for two of the three years.

Wise et al. (1967) at the North Carolina Station reported that steers grazing Coastal bermudagrass pasture alone gained an average of 1.15 pounds daily. Supplementation with 1.5 pounds of soybean meal resulted in a 0.25-pound per day increase in gain. Grazing steers were self-fed 80% corn plus 10% soybean meal plus 10% animal fat, or 90% corn plus 10% animal fat. These rations self-fed on grass resulted in daily gains of approximately 2.2 pounds, with added protein producing only 0.1 pound more gain per head daily. Carcasses produced by pasture alone or pasture plus soybean meal were primarily Standard, while those produced on the self-fed treatment were primarily Good with a few Choice carcasses.

PROCEDURE

Treatment of Pastures

Pastures used were fescuegrass, Coastal bermudagrass, and common bermudagrass. All pastures were on established plots with a good stand of grass. The fescuegrass pastures were topdressed with 67 pounds of nitrogen per acre each September and with 33.5 pounds of nitrogen per acre in February or March of each year. Bermudagrass pastures were topdressed with 67 pounds of nitrogen per acre each April and with 33.5 pounds of nitrogen per acre in July or August. Both Coastal and common bermudagrass pastures were overseeded each November with common ryegrass at the rate of 25 pounds per acre. After the ryegrass seeding, each bermudagrass pasture was topdressed with 33.5 pounds of nitrogen per acre. All pastures furnished abundant, high-quality forage.

Handling of Cattle

Weanling beef steer calves were purchased each year in October. These calves averaged 453 pounds and graded Good. All calves were number-branded soon after arriving on the Station. They were wormed approximately two weeks after purchase and again in May of the following year. They were sprayed to control lice, and back-rubbers were provided to control flies. Each calf received a 24-milligram implant of diethylstilbestrol in October and a second implant of 24 milligrams in May.

Each year the 60 beef calves were assigned at random to one of five treatments and placed on pasture. Each group of 12 calves had access to 12 acres of pasture. The pastures available to each group were four acres of fescuegrass, four acres of Coastal bermudagrass, and four acres of common bermudagrass.

The grazing of pastures was divided into two periods. The 196 days from November to May were considered as the winter pasture period and the 103 days from May to September were considered as the summer grazing period. In addition to the grazing, each lot was self-fed one of the rations shown in Table 1 for 299 days.

All rations contained salt or salt and whole cottonseed. An attempt was made to formulate these rations so that the daily intake would be approximately 1% of the animal's live weight. Only one ration (II) contained urea.

Previous research at this Station has shown that pastures can be stocked at the rate of one and one-half to two steers per acre when a

TABLE 1.—Concentrate Rations[1]

Feedstuff	Ration number[2] I	II	III	IV	V
Yellow corn meal, lb.	1,440	1,760	1,690	1,490	1,790
Cottonseed, lb.	300			250	
Urea, lb.		30			
Calcium carbonate, lb.	10	10	10	10	10
Salt, lb.	250	200	300	250	200
Total, lb.	2,000	2,000	2,000	2,000	2,000

[1] Aureomycin was added to each ration at the level of 70 mg/5 lb. of feed.

[2] The calculated crude protein contents of the rations were 9.9, 11.4, 7.6, 9.6, and 8.1%, respectively.

grain supplement is furnished in addition to the grazing. But in this experiment pastures were purposely stocked at the rate of one steer per acre so that grass would not be a limiting factor.

The following orthogonal comparisons were made between ration treatment types: (1) supplemental protein (rations I, II, and IV) vs. no supplemental protein (rations III and V); (2) 15% salt (ration III) vs. 10% salt (ration V); (3) urea-containing ration (II) vs. cottonseed-containing rations (I and IV); and (4) 15% cottonseed (ration I) vs. 12.5% cottonseed (ration IV).

RESULTS AND DISCUSSION

Results of the winter feeding and grazing period are presented in Table 2. During this period the highest daily gain was made by the steers fed ration II, although little difference in gain existed among rations II, IV, and V, and the lowest gain was made by the steers fed ration III. Steers fed the rations (III and V) containing no supple-

TABLE 2.—Three-Year Average Results of Feeding and Grazing Winter Pastures (November-May; 196 Days) 1966-69

Item[1]	Ration number I	II	III	IV	V
Number of animals/year	12	12	12	12	12
Final weight, lb.	816	837	777	838	834
Initial weight, lb.	455	450	452	454	452
Total gain/steer, lb.	361	387	325	384	382
Daily gain, lb.	1.84	1.97	1.66	1.96	1.95
Concentrate intake/head/day, lb.	6.66	6.76	2.73	4.34	5.67
Concentrate intake/lb. gain, lb.[2]	3.58	3.49	1.67	2.27	2.97

[1] All values, where applicable, are averages.

[2] Means adjusted for unequal numbers per treatment.

mental protein gained, on the average, significantly less than steers fed rations containing additional protein. The 15% salt in ration III restricted concentrate consumption too much to support adequate gain. Steers fed ration III gained significantly less than steers fed ration V, which explains why these two rations when considered together as one treatment effect (no supplemental protein) were inferior to the other three rations in producing gain. The concentrate intake per pound of gain was highest for the group fed ration I and lowest for the steers receiving ration III. Steers fed 15% cottonseed in the ration (I) gained significantly less than those fed 12.5% cottonseed (IV).

During the period of summer grazing (Table 3) the steers fed the 10% salt and 90% corn ration (V) produced the highest daily gain. Steers fed no supplemental protein (rations III and V) gained significantly faster than steers receiving protein supplements. This response is probably a reflection of slower gains during the winter period. Both of the lots consuming whole cottonseed (rations I and IV) produced low daily gains during the summer period. The ration containing urea (II) produced superior gains when compared with the two similar rations containing cottonseed as a protein source. The consumption of the 15% salt ration (III) was markedly increased during this period as the steers increased in body weight.

TABLE 3.—Three-Year Average Results of Feeding and Grazing Summer Pastures (May-September; 103 Days) 1966-69

	Ration number				
Item[1]	I	II	III	IV	V
Number of animals/year	12	12	12	12	12
Final weight, lb.	945	978	920	964	981
Initial weight, lb.	816	837	777	838	834
Total gain/steer, lb.	129	141	143	126	147
Daily gain, lb.	1.25	1.37	1.39	1.22	1.43
Concentrate intake/head/day, lb.	8.11	10.11	6.25	7.65	8.96
Concentrate intake/lb. gain, lb.[2]	6.75	7.55	4.54	6.49	6.48

[1] All values, where applicable, are averages.

[2] Means adjusted for unequal numbers per treatment.

Daily gains were satisfactory in all lots for the 299-day combined grazing season (Table 4). The daily concentrate consumption for four of the lots was approximately 1% of the animal's body weight, while the steers having access to the 15% salt ration consumed only about 0.5% of their body weight. Steers consuming the urea-containing ration required more feed per pound of gain than the steers fed the other rations. The individual daily concentrate consumption of the ration containing urea was 1.11 pounds greater than the consumption of the

TABLE 4.—Three-Year Average Results of Feeding and Grazing Winter and Summer Pastures (November-September; 299 Days) 1966-69

	Ration number				
Item[1]	I	II	III	IV	V
Live animal data					
Number of animals/year	12	12	12	12	12
Final weight, lb.	945	978	920	964	981
Initial weight, lb.	455	450	452	454	452
Total gain/steer, lb.	490	528	468	510	529
Daily gain, lb.	1.64	1.77	1.57	1.71	1.77
Total feed intake/steer, lb.	2141	2366	1179	1639	2034
Concentrate intake/head/day, lb.	7.16	7.91	3.94	5.48	6.80
Concentrate intake/lb. gain, lb.[2]	4.37	4.47	2.51	3.20	3.84
Carcass data					
Weight, lb.	535	552	495	538	556
Starting grade—live	10.9	10.9	11.1	11.2	11.0
Final grade—carcass	10.2	10.5	9.55	9.81	10.4
Dressing percent[3]	60.12	59.94	57.89	59.10	60.41
Fat thickness, inches	.36	.38	.28	.33	.37
Yield grade	2.62	2.56	2.29	2.45	2.57
Rib eye muscle area, sq. in.	10.19	10.28	9.65	10.19	10.36

[1] All values, where applicable, are averages.

[2] Means adjusted for unequal numbers per treatment.

[3] Dressing percent is the warm carcass weight less 2% divided by the weight prior to slaughter.

same ration without urea (V). Steers consuming rations containing 10% salt (II and V) had greater daily gains than steers consuming other rations. As a general rule, the greater the daily concentrate intake, the greater was the concentrate intake per pound of gain (Table 4).

Carcass data for the 180 steers are presented in Table 4. The carcass weight each year ranged from 500 to 560 pounds, which is a very popular weight. Dressing percent was lowest for steers consuming ration III, but was very close in the other four lots. Yield grades on all carcasses were very good. The rind fat averaged from 0.28 to 0.38 inch, which is a very desirable thickness. Steers consuming the grain mixtures containing no protein supplement had, on the average, significantly less rind fat than steers consuming protein supplemented rations. The steers receiving no protein supplement averaged less rib eye area than the average for the steers consuming the other three rations. Further analysis indicated that the steers consuming the higher salt-containing ration (III) had significantly less rind fat and rib eye area than the steers consuming ration V. The differences in performance and carcass data between feeding no supplemental protein (rations III and V) and feeding protein are probably not the result of the protein level, but rather the result of the low consumption of ration III, which was a function of the level of salt in the ration.

It should be noted in Table 4 that the final carcass grade was not as high in any of the lots as the starting live grade. In earlier work (Carpenter et al., 1968), concentrates were hand-fed at 1% of the animal's live weight. Thus the amount of concentrates increased as steers increased in weight. The Choice grade was obtained in 45% of the carcasses from steers fed in this manner. When self-fed on pasture the steers did not increase intake on this schedule, thus accounting in part for the lower grades of the carcasses in these trials.

Carcass grades for the three trials are presented in Table 5. In two of the three trials there were no Choice carcasses produced; a large percentage were in the high Good grade, however. This would indicate that with the amount of feed consumed, a slightly longer feeding and grazing period was needed. The highest grading carcasses, as an average for the three years, were produced in the lot receiving ration II. The carcass grades by ration, from the highest to the lowest, were as follows: Ration II, V, I, IV, and III. Carcass grades were very similar for animals receiving the first four rations listed above. Animals consuming ration III had significantly lower carcass grades than steers receiving a similar ration containing less salt (V).

TABLE 5.—Carcass Grades for Cattle Fed During the Three-Year Period (180 Steers)

Ration	Grade							
	Choice +	Choice	Choice −	Good +	Good	Good −	Standard +	Standard
I		2	4	7	13	7	3	
II	1	2	3	9	13	8		
III		1		4	14	14	2	1
IV		1	1	5	16	12	1	
V		5	2	6	16	3	4	

SUMMARY

Previous work at the Northeast Louisiana Agricultural Experiment Station and the Macon Ridge Branch Station has shown that weanling beef steer calves can be held economically for feeding on pasture until ready for slaughter. With increases in land prices and the cost of maintaining a cow, this approach to finishing slaughter steers is becoming more popular.

Earlier studies indicated that a daily concentrate intake of 1% of the animal's live weight on pasture was sufficient to produce the grade and weight carcasses in demand on today's market. Self-feeding on pasture was considered as a means of reducing labor costs and the daily chore of feeding. The work reported herein compares five rations self-fed to grazing steers for a period of 299 days.

As indicated by the results of this study, steer calves can be finished on pasture with a limited amount of concentrates. Generally speaking, less labor and feeding know-how are required in a pasture fattening program where the concentrates are self-fed. There is considerable potential in Louisiana and the southern United States for using good-quality pasture and a limited amount of grain in a steer fattening program.

All rations used in this study produced acceptable gains, carcass weights, and grades. It is possible that in certain years the length of feeding should be increased by 25 to 30 days. In the future, if grain prices become favorable, more feeding may be done in this area, but at present most of the nutrients for beef cattle in any program should be furnished by good-quality pastures.

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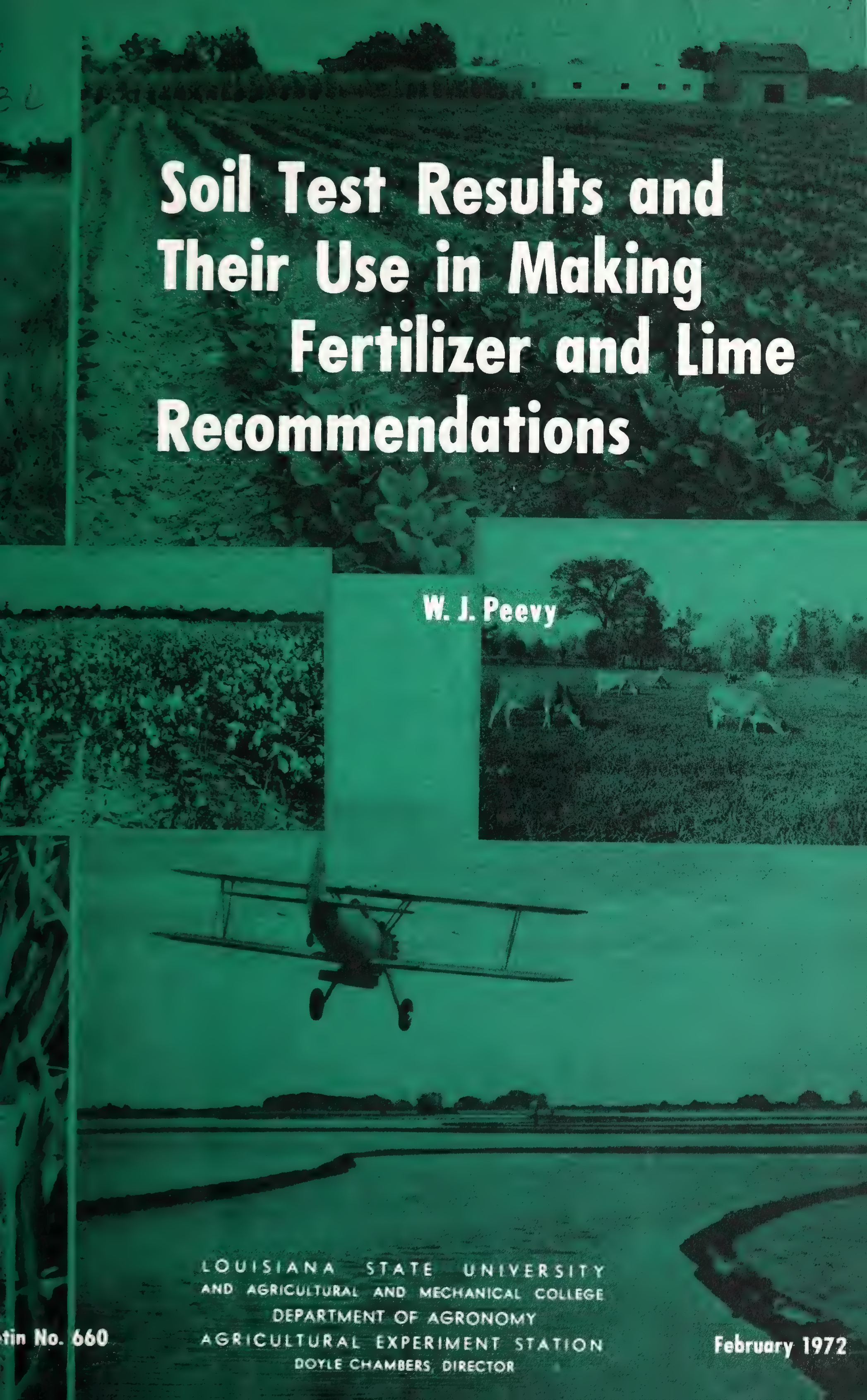

Soil Test Results and Their Use in Making Fertilizer and Lime Recommendations

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Soil Test Results and Their Use In Making Fertilizer and Lime Recommendations

W. J. Peevy[1]

INTRODUCTION

Many farmers now use soil tests as a guide for their fertilizer applications. The parish employees of the Louisiana State University Cooperative Extension Service have the major responsibility of assisting Louisiana farmers with the use of soil test data in making decisions about the use of fertilizers and lime.

The tables in this publication were prepared to assist Cooperative Extension Service employees and others who may be involved in assisting farmers, as well as to assist those farmers who make their own decisions from soil test data.

The data in Table 1 are used as a general guide to interpret soil analysis for agronomic crops. The use of the word "available" is being discontinued. Instead of using the term "available" phosphorus, the term "extractable" phosphorus is used. There has not been any change in the procedure used—just a change in terms. Also, for potassium, calcium and magnesium, the results are now reported as "exchangeable" instead of "available."

What Do the Terms Extractable and Exchangeable Mean?

For phosphorus, the term "extractable" means the amount of phosphorus that can be dissolved by the use of a solution containing 0.1 *N* hydrochloric acid and 0.03 *N* ammonium fluoride. The amount of phosphorus that plants can obtain from a soil is related to the amount that can be extracted by using this solution.

For potassium, calcium and magnesium, the term "exchangeable" means the amounts of these ions that can be removed from the clay and organic colloids. They are held by these soil fractions in exchangeable positions. They can be removed (or exchanged) by adding some other ions (such as H^+ or NH_4^+). All of the amount that is "exchanged" is not "available" to plants, but the amount that plants can obtain is related to the amount of exchangeable ions.

In the Red River floodplain and some other alkaline soils, the calcium and magnesium reported includes not only the "exchangeable" forms, but also some of these elements that come directly from limestone particles contained in these calcareous soils.

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Making Nitrogen, Phosphorus and Potassium Recommendations

Tables 2 through 19 have been prepared as guides for making $N-P_2O_5-K_2O$ recommendations for soils that have very low, low, medium or high amounts of extractable phosphorus and exchangeable potassium.

Examine Table 2 for an example of the way these tables can be used for agronomic crops. About 100 lbs. of nitrogen are recommended at planting time for the pastures of Table 2. Therefore, 100 is listed as the nitrogen recommendation at all P and K levels. If the soil is very low in extractable phosphorus and very low in exchangeable potassium, the recommendation would be 100-80-80. If the extractable phosphorus is very low and the potassium is medium, the suggested recommendation is 100-80-40. On the other hand, if the extractable phosphorus is high and the exchangeable potassium is medium, the suggested recommendation is 100-0-40. Even in such cases where the phosphorus is high, some farmers may prefer to use a little phosphorus as a "starter" and to help maintain the high phosphorus status of the soil.

In all other tables the same procedure is used. The extractable phosphorus ratings are listed across the top of each table, and the exchangeable potassium ratings are listed down the left side of each table. Use the data in Table 1 to determine the soil test ratings, then refer to the table with the crop and soil area for which the fertilizer recommendation is to be made.

Making Limestone Recommendations

The data in Table 1 also include the levels of calcium and magnesium that are used to interpret soil test results. In addition to these data, the soil test results also show the effects of limestone on soil pH, and the amount of lime needed to adjust pH can be determined from this information. However, the *kind* of limestone that a farmer should apply depends on the calcium and magnesium levels in his soil. If calcium is low and magnesium is medium to high, he should use calcic (calcium carbonate) limestone. If both calcium and magnesium are low, he should use dolomitic limestone (containing both calcium carbonate and magnesium carbonate). It should be remembered that the *main purpose* of adding limestone is very often to supply calcium and/or magnesium as plant nutrients instead of reducing soil acidity. Therefore, it is important to add the lime that supplies the element or elements needed.

The use of 1 ton of pure calcium carbonate ground agricultural limestone will add about 200 ppm of exchangeable calcium to an acre of soil. The use of dolomitic (high grade) ground agricultural limestone will add only about 100 ppm of exchangeable calcium and about 60 ppm of exchangeable magnesium. Therefore, if a farmer's soil has medium to high magnesium and low calcium content, it is obvious that he should apply calcium carbonate limestone.

General Soil Areas	Extractable Phosphorus ppm		Textures and Approximate Cation Exchange Capacities		EXCHANGEABLE									
			Texture	Cation Exchange Capacity meq/100g. soil	Potassium ppm				Calcium ppm			Magnesium ppm		
					Very Low	Low	Medium	High	Low	Medium	High	Low	Medium	High
Coastal Plains	Very Low	10												
	Low	10–40	Sandy Loams	4	40	40–60	60–100	100	500	500–700	700	50	50–70	70
	Medium	40–80	Very Fine Sandy Loams	6	50	50–80	80–120	120	700	700–900	900	70	70–90	90
	High	80												
Flatwoods	Very Low	10												
	Low	10–35	Very Fine Sandy Loams	6	50	50–80	80–120	120	700	700–1000	1000	70	70–100	100
	Medium	35–70	Silt Loams	8	60	60–100	100–140	140	1000	1000–1300	1300	100	100–130	130
	High	70												
Mississippi Terraces and Loessial Hills	Very Low	10												
	Low	10–35	Silt Loams	8	60	60–100	100–140	140	1000	1000–1300	1300	100	100–130	130
	Medium	35–70	Silt Loams	10	80	80–120	120–160	160	1200	1200–1600	1600	120	120–160	160
	High	70												
Coastal Prairies	Very Low	10												
	Low	10–30	Very Fine Sandy Loams	8	60	60–100	100–140	140	1000	1000–1300	1300	100	100–130	130
	Medium	30–70	Silt Loams	10	80	80–120	120–160	160	1200	1200–1600	1600	120	120–160	160
	High	70	Clay Loams	15	100	100–160	160–200	200	1800	1800–2400	2400	180	180–240	240
Red, Ouachita and Miss. River Alluvial Soils Very Fine Sandy Loams and Silt Loams	Very Low	40	Loamy Sands	4	40	40–60	60–100	100	500	500–800	800	50	50–80	80
	Low	40–60	Very Fine Sandy Loams	8	60	60–100	100–140	140	1000	1000–1300	1300	100	100–130	130
	Medium	60–120	Silt Loams	10	80	80–120	120–160	160	1200	1200–1600	1600	120	120–160	160
	High	120	Silt Loams	15	100	100–160	160–220	220	1800	1800–2400	2400	180	180–240	240
Red, Ouachita and Miss. River Alluvial Soils Clay Loams and Clays	Very Low	60	Clay Loams (32% Clay)	20	140	140–200	200–300	300	2400	2400–3200	3200	240	240–320	320
	Low	60–80	Clays (40% Clay)	25	160	160–240	240–360	360	3000	3000–4000	4000	300	300–400	400
	Medium	80–160	Clays (50% Clay)	30	180	180–280	280–420	420	3600	3600–4800	4800	360	360–480	480
	High	160	Clays (60% Clay)	40	240	240–340	340–510	510	4800	4800–6400	6400	480	480–640	640

Table 2.—Recommendations for wheat, ryegrass or oats for grazing

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	– – – – – – – – – Pounds N–P_2O_5–K_2O per acre – – – – – – – –			
Very Low	100–80–80	100–60–80	100–40–80	100–0–80
Low	100–80–60	100–60–60	100–40–60	100–0–60
Medium	100–80–40	100–60–40	100–40–40	100–0–40
High	100–80–0	100–60–0	100–40–0	100–0–0

Apply, at planting, 100 lbs. of nitrogen and the recommended phosphorus and potassium. This should be done about September 1-15 in north Louisiana and about September 15 to October 1 in south Louisiana.

These crops should not be grazed until they are about 12 inches tall. The stocking rate should be 500 to 600 lbs. per acre when the plants are 12 inches tall. Animals should be rotated on two or more pastures. The plants should not be grazed closer than 2 to 3 inches.

More nitrogen may be needed after the pastures have been grazed heavily. These plants will produce a large amount of grazing when properly fertilized and managed.

Table 3.—Recommendations for wheat or oats for grain on alluvial soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	– – – – – – – – – Pounds N–P_2O_5–K_2O per acre – – – – – – – –			
Very Low	60–80–80	60–60–80	60–40–80	60–0–80
Low	60–80–60	60–60–60	60–40–60	60–0–60
Medium	60–80–40	60–60–40	60–40–40	60–0–40
High	60–80–0	60–60–0	60–40–0	60–0–0

When these crops are grown for grain only, no nitrogen is usually needed in the fall. On light, sandy soils where organic matter is low, use 15 to 30 lbs. of nitrogen at planting and 60 lbs. about March 1.

The phosphorus and potassium, when needed, should be applied at or just before planting.

The nitrogen needed for topdressing should be applied March 1-15.

If these crops are to be used for grazing and grain production, apply 60 or more pounds of nitrogen at planting, then apply more when the cattle are removed about March 1.

Table 4.—Recommendations for wheat or oats for grain on soils outside of alluvial areas

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N-P_2O_5-K_2O$ per acre — — — — — — — —			
Very Low	80–80–80	80–60–80	80–40–80	80–0–80
Low	80–80–60	80–60–60	80–40–60	80–0–60
Medium	80–80–40	80–60–40	80–40–40	80–0–40
High	80–80–0	80–60–0	80–40–0	80–0–0

Apply the phosphorus and potassium and 15 to 30 lbs. of nitrogen in the fall at or just prior to planting. Apply the remainder of the nitrogen about March 1.

Be sure the soils are limed to pH 6.0 - 6.5.

When wheat and oat varieties are developed that have stronger straw, more nitrogen can be used with less loss from lodging.

Table 5.—Recommendations for winter clover followed by summer grasses

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N-P_2O_5-K_2O$ per acre — — — — — — — —			
Very Low	60–120–120	60–100–120	60–60–120	60–40–120
Low	60–120–100	60–100–100	60–60–100	60–40–100
Medium	60–120–60	60–100–60	60–60–60	60–40–60
High	60–120–40	60–100–40	60–60–40	60–40–40

Be sure the soil is properly limed before establishing such pastures.

If the grass is planted first on such pastures, apply about one-half of the recommended phosphorus and potassium at or just before planting. Apply the other phorphorus and potassium about October 15 to November 1 for clover. The nitrogen should be applied in June.

In the fall — by October 15 — remove all grass growth so that the clover can survive. This is necessary every fall. Apply the recommended phosphorus and potassium in the fall at the time the clover is expected to start growing — about October 15 to November 1.

More phosphorus and potassium are needed for clover-grass pasture than when clover is grown alone, because of the double cropping.

Table 6.—Recommendations for clover grown alone

Exchangeable potassium (ppm)	Extractable phosphorus (ppm) Very Low	Low	Medium	High
	– – – – – – – – Pounds N–P_2O_5–K_2O per acre – – – – – – – –			
Very Low	0–90–90	0–60–90	0–40–90	0–0–90
Low	0–90–60	0–60–60	0–40–60	0–0–60
Medium	0–90–40	0–60–40	0–40–40	0–0–40
High	0–90–0	0–60–0	0–40–0	0–0–0

Before fertilizing to grow clover, make certain that the soil has sufficient lime to raise the pH to above 6, and also be sure that the exchangeable calcium and magnesium are in sufficient supply.

The phosphorus and potassium should be applied at the time that clover is expected to start growing, which is usually October 15 to November 1 in Louisiana. The phosphorus and potassium in mixed fertilizer or in phosphorus and potassium carriers (such as superphosphate and muriate of potash) are very readily available when applied.

When large amounts of phosphorus are applied to properly limed soils, the extractable phosphorus will increase in that soil, and less will be needed as this build-up occurs. Exchangeable potassium does not accumulate much in most soils, especially in sandy loam soils. Therefore, it will generally be necessary to continue using the recommended amounts.

Table 7.—Recommendations for coastal bermudagrass, common bermudagrass, bahiagrass or dallisgrass for 5 to 6 tons of forage or hay on alluvial soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm) Very Low	Low	Medium	High
	– – – – – – – – Pounds N–P_2O_5–K_2O per acre – – – – – – – –			
Very Low	200–80–100	200–60–100	200–40–100	200–0–100
Low	200–80–60	200–60–60	200–40–60	200–0–60
Medium	200–80–40	200–60–40	200–40–40	200–0–40
High	200–80–0	200–60–0	200–40–0	200–0–0

All of the phosphorus needed may be applied in one application. The nitrogen should be applied in two or more applications in order to have a more even production of forage and of protein in the forage. These grasses begin to grow about March 15 in South Louisiana and April 1 in North Louisiana. The first application of fertilizer should be made about the time the grass is expected to begin spring growth.

If three applications of nitrogen are to be used, apply about 50 to 60 pounds March 15 to April 1, then apply about 70 pounds about June 1 and 70 pounds about August 1. There will be dry periods when some of this nitrogen will not be used immediately after application. However, materials not containing urea can be applied in hot weather and will remain until rains come.

When large amounts of potassium are needed, it should also be applied in split applications, at the same time the nitrogen is applied.

Table 8.—Recommendations for coastal bermudagrass for 8 to 10 tons of hay

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N-P_2O_5-K_2O$ per acre — — — — — — — —			
Very Low	400–120–240	400–100–240	400–60–240	400–40–240
Low	400–120–200	400–100–200	400–60–200	400–40–200
Medium	400–120–100	400–100–100	400–60–100	400–40–100
High	400–120–40	400–100–40	400–60–40	400–40–40

When phosphorus is needed, it may be applied in one application for the entire year.

When potassium is needed, it should be applied in split applications, preferably each time nitrogen is applied, or at least in two or more applications.

Nitrogen should be applied first in the early spring, about March 15 to April 1, and then more should be applied immediately after each cutting, except that none is needed *after* the last cutting in the fall.

If five (5) cuttings are to be made at about monthly intervals, then make five nitrogen applications of 80 lbs. each. If four (4) cuttings are to be made at 5- to 6-week intervals, then make four applications of about 100 lbs. each.

Table 9.—Recommendations for common bermudagrass, coastal bermudagrass, bahiagrass or dallisgrass for 4 to 5 tons of forage or hay on soils outside of alluvial areas

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N-P_2O_5-K_2O$ per acre — — — — — — — —			
Very Low	*200–100–120	200–80–120	200–60–120	200–40–120
Low	200–100–100	200–80–100	200–60–100	200–40–100
Medium	200–100–60	200–80–60	200–60–60	200–40–60
High	200–100–40	200–80–40	200–60–40	200–40–40

*Split applications.

Many of these soils are strongly acid and low in exchangeable calcium and magnesium. Lime should be applied to correct these deficiencies.

Apply phosphorus in one application in the spring.

Apply the potassium in split applications, preferably each time nitrogen is applied.

The nitrogen should be applied in split applications. When as much as 200 lbs. of nitrogen are used, apply in three applications of about 67 lbs. each. If only 100 to 150 lbs. of nitrogen are used, make two or three applications. When much more than 200 lbs. are used, make more than three applications.

Table 10.—Recommendations for rice on coastal prairie, Mississippi terrace or flatwoods soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N-P_2O_5-K_2O$ per acre — — — — — — — —			
Very Low	80–60–60	80–40–60	80–20–60	80–0–60
Low	80–60–40	80–40–40	80–20–40	80–0–40
Medium	80–60–0	80–40–0	80–20–0	80–0–0
High	80–60–0	80–40–0	80–20–0	80–0–0

FOR WATER-PLANTED RICE

All of the phosphorus and potassium should be applied pre-plant and worked into the soil 2 to 4 inches deep. If the phosphorus and potassium can not be applied pre-plant, they should be applied no later than the first flood.

If the soil is kept flooded, or if drained briefly but kept saturated, all the nitrogen may also be applied pre-plant.

If the soil is drained for a period of 2 to 3 weeks which permits the soil to dry, one-half of the nitrogen should be applied just before the first flood and the remainder should be applied at first joint.

FOR DRILLED RICE

Where the fertilizer and seed are drilled together, all of the phosphorus and potassium and up to half of the nitrogen may be applied at planting. The remainder of the nitrogen should be applied at about the first joint.

When the fertilizer and seed are separated as much as 2 inches, all of the fertilizer may be applied at planting.

Table 11.—Recommendations for cotton on alluvial soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	Pounds N-P_2O_5-K_2O per acre			
Very Low	*120-80-80	120-60-80	120-40-80	120-0-80
Low	120-80-60	120-60-60	120-40-60	120-0-60
Medium	120-80-40	120-60-40	120-40-40	120-0-40
High	120-80-0	120-60-0	120-40-0	120-0-0

*Less N should be used when O. M. is high (3-4%).

Large amounts of nitrogen are used by cotton plants in producing high yields. About 75 lbs. of nitrogen are used for each bale produced.

The amount of nitrogen needed on farms will vary. The organic matter content of a soil will supply some nitrogen. Deep soils will have more nitrogen supplied from organic matter than will be supplied in shallow soils with the same percent of organic matter. Soils with good moisture holding capacity will supply more nitrogen than soils which tend to dry fast.

Therefore, the *size of stalk* that a field produces should be used in helping to determine how much nitrogen to apply. Where stalks grow too large, reduce the nitrogen application. If stalks are too small, increase nitrogen applications, and also check to see if the land needs deep breaking.

All of the phosphorus and potassium should be applied in the soil at or before planting. All of the nitrogen may be applied then, or some of it may be applied as a side-dressing.

When weed and grass control is not good, all of the fertilizer should be placed fairly deep. This is also a good practice even with good weed and grass control.

Table 12.—Recommendations for cotton on coastal plain, Mississippi terrace, flatwoods or coastal prairie soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	Pounds N-P_2O_5-K_2O per acre			
Very Low	90-80-80	90-60-80	90-40-80	90-20-80
Low	90-80-60	90-60-60	90-40-60	90-20-60
Medium	90-80-40	90-60-40	90-40-40	90-20-40
High	90-80-20	90-60-20	90-40-20	90-20-20

Many of these soils are strongly acid. Lime them to at least pH 6.0. Do not over-lime them because, in doing so, deficiencies of some of the micronutrients may be created.

Most of these soils are deficient in organic matter and, therefore, deficient in nitrogen. Because of moisture deficiencies that often occur in these soils, yields are limited, even with fertilizer applications. About 90 lbs. will usually be as much nitrogen as moisture will permit to be used.

All of the phosphorus and potassium and some or all the nitrogen should be applied at or before planting.

Table 13.—Recommendations for soybeans

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds $N\text{-}P_2O_5\text{-}K_2O$ per acre — — — — — — — —			
Very Low	0–90–90	0–60–90	0–30–90	0–0–90
Low	0–90–60	0–60–60	0–30–60	0–0–60
Medium	0–90–30	0–60–30	0–30–30	0–0–30
High	0–90–0	0–60–0	0–30–0	0–0–0

Soybeans need well limed, fertile soils. The pH, calcium and magnesium levels are important. On some alluvial soils, sufficient calcium may be present at pH levels of about 6.0. On many of the soils outside of the alluvial areas, and also in some of the older alluvial soils, it may be necessary to raise the pH to 6.5-7.0 for best results. Recent work at Baton Rouge on Mississippi terrace soils indicates that a pH of 6.5 or higher is needed for best yields.

Where phosphorus is very low, rather large amounts should be *added to well limed soils* in order to raise the fertility status of the soil for higher yields.

Where potassium is needed, it should be applied annually.

Nitrogen is not needed for properly inoculated soybeans.

Response has been obtained from the use of molybdenum applied at the rate of ¼ ounce per acre on soils that have a pH between 5.2 and 6.2. If the pH is below 5.2, it is generally too acid for response to molybdenum. If it is above 6.2, the molybdenum content of the soil will usually be available in sufficient quantity.

Even though response may be obtained from molybdenum on soils with between 5.2 and 6.2, the continued use of such soils for soybeans without the application of lime will most likely result in very poor yields in years ahead, even with the use of molybdenum.

It should be remembered that, in many ways, a properly limed soil is the *foundation* on which soil fertility is built.

Table 14.—Recommendations for sugarcane (plant cane)

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds N–P_2O_5–K_2O per acre — — — — — — — —			
Very Low	80–60–120	80–40–120	80–20–120	80–0–120
Low	80–60–80	80–40–80	80–20–80	80–0–40
Medium	80–60–40	80–40–40	80–20–40	80–0–40
High	80–60–0	80–40–0	80–20–0	80–0–0

The amount of nitrogen needed will vary. If the soil contains about 3 percent organic matter or more, less than 80 pounds is probably needed. Where low amounts of organic matter are present (1-1.5 percent in light soils; 2-2.5 percent in heavy soils), more than 80 pounds may be needed.

Also, where large amounts of summer legume crops, such as soybeans, have been turned under prior to planting cane, less than 80 pounds may be needed.

The phophorus, potassium and nitrogen should be applied in the early spring. They should be placed in the soil several inches deep.

Annual applications will be needed as recommended. After several years of phosphorus application in well limed soils, the phosphorus availability will increase and then the rate of application can be reduced. There is not much accumulation of potassium in soils.

Table 15.—Recommendations for sugarcane (stubble cane) on light-textured soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds N–P_2O_5–K_2O per acre — — — — — — — —			
Very Low	120–60–120	120–40–120	120–20–120	120–0–120
Low	120–60–80	120–40–80	120–20–80	120–0–80
Medium	120–60–40	120–40–40	120–20–40	120–0–40
High	120–60–0	120–40–0	120–20–0	120–0–0

The phosphorus, potassium and nitrogen should be applied in the early spring. They should be placed several inches deep in the soil.

Table 16.—Recommendations for sugarcane (stubble cane) on heavy-textured (clay) soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds N–P_2O_5–K_2O per acre — — — — — — — —			
Very Low	140–60–120	140–40–120	140–20–120	140–0–120
Low	140–60–80	140–40–80	140–20–80	140–0–80
Medium	140–60–40	140–40–40	140–20–40	140–0–40
High	140–60–0	140–40–0	140–20–0	140–0–0

The phosphorus, potassium and nitrogen should be applied in the early spring. They should be placed several inches deep in the soil.

Table 17.—Recommendations for corn on alluvial soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	— — — — — — — — Pounds N–P_2O_5–K_2O per acre — — — — — — — —			
Very Low	150–100–100	150–80–100	150–60–100	150–40–100
Low	150–100–80	150–80–80	150–60–80	150–40–80
Medium	150–100–40	150–80–40	150–60–40	150–40–40
High	150–100–0	150–80–0	150–60–0	150–40–0

When phosphorus and potash are needed, they should be applied before planting and bedded on. When liquid fertilizers are used, they can be "knifed" into a prepared seedbed. On most soils, some nitrogen should also be put in the soil—such as in 5-20-20, 6-24-24, 4-11-11 or similar grades. All of the nitrogen may be put deep under the row, or some of it may be applied as a side-dressing. This side-dressing should be done when the corn is not over 12 to 24 inches high, and it should be placed in the middle—and preferably 6 to 12 inches deep.

When broadcast herbicides are used, all of the fertilizers should be applied first.

On strongly acid soils, lime them to about pH 6.0-6.5.

Table 18.—Recommendations for grain sorghum on alluvial soils

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	Pounds N–P_2O_5–K_2O per acre			
Very Low	120–80–80	120–60–80	120–40–80	120–0–80
Low	120–80–60	120–60–60	120–40–60	120–0–60
Medium	120–80–40	120–60–40	120–40–40	120–0–40
High	120–80–0	120–60–0	120–40–0	120–0–0

Apply the phosphorus, potassium and some of the nitrogen under the row. All of the nitrogen may be placed under the row, or some of it may be added as a side-dressing. If applied as a side-dressing, it should be applied early and far enough away from plants to avoid severe root damage.

Make sure that soil pH is at least 6.0-6.5.

Table 19.—Recommendations for corn or grain sorghum on soils outside of alluvial areas

Exchangeable potassium (ppm)	Extractable phosphorus (ppm)			
	Very Low	Low	Medium	High
	Pounds N–P_2O_5–K_2O per acre			
Very Low	100–80–80	100–60–80	100–40–80	100–20*–80
Low	100–80–60	100–60–60	100–40–60	100–20*–60
Medium	100–80–40	100–60–40	100–40–40	100–20*–40
High	100–80–0	100–60–0	100–40–0	100–20*–0

*Starter and maintenance.

Many soils outside of the alluvial soil areas need lime. All strongly acid soils should be limed to pH 6.0-6.5 for these crops.

Apply the phosphorus and potassium and some of the nitrogen under the row. All of the nitrogen may be placed deep under the row, or some of it may be applied as a side-dressing. Any side-dressing should be done when the plants are fairly young to help prevent damage to the roots by the fertilizer itself or by the applicator equipment.

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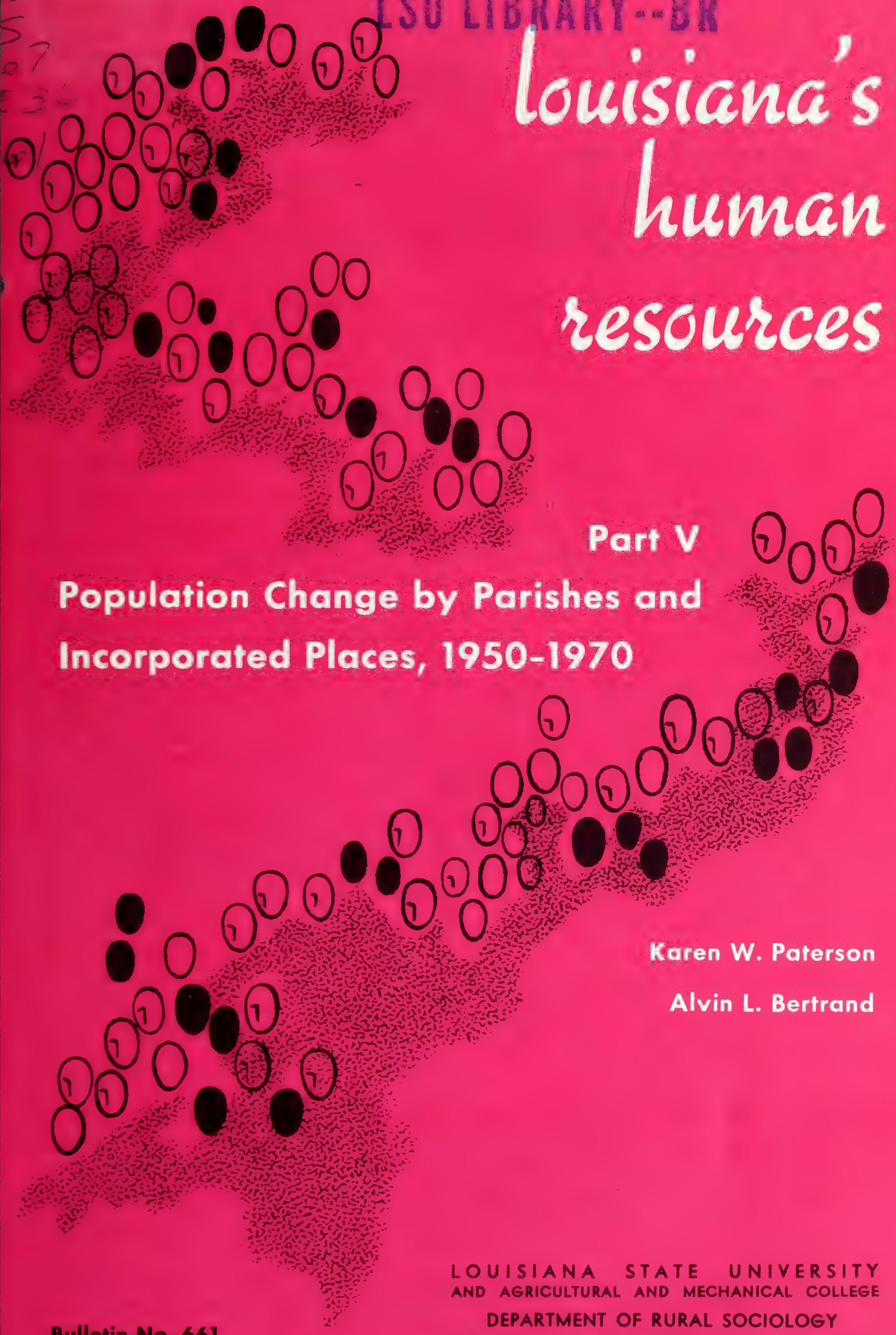

Part V

Population Change by Parishes and Incorporated Places, 1950-1970

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DEPARTMENT OF RURAL SOCIOLOGY
AGRICULTURAL EXPERIMENT STATION
DOYLE CHAMBERS, DIRECTOR

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Louisiana's Human Resources

Part V: Population Change by Parishes and Incorporated Places, 1950-1970

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Introduction

This bulletin follows a tradition long established in the Department of Rural Sociology of the Louisiana Agricultural Experiment Station. It was prepared as a service to the people of the state, in the sense that many individuals and agencies have use for basic population information. The timeliness of the report stems from the fact that detailed findings from the Nineteenth Decennial Census are just now becoming available.

The data presented have been organized in such a way as to make it easy to determine numbers, distributions and trends. Louisiana, as other states, is the scene of continual change. There is perhaps no better indicator of this change than the data relating to its human resources. In this regard, it is fundamental that those who would plan for the state know how many people they have to plan for and the characteristics of these people. It is hoped that the data provided in this and succeeding bulletins in this series will be useful in this manner.

Number of Inhabitants

The final counts of the 1970 Decennial Census revealed that the population of Louisiana had reached 3,643,180[1] at the time the second or follow-up counts of the Census were made. With this number of inhabitants, the state ranked 20th in size among the 50 states. It is interesting to note that the state ranked 20th in size among all the states in 1960, and that it has not changed its position.

A total of 203,184,772 people were counted in the United States as a whole in April of 1970. This represented an increase of 23,861,597 persons in the 10-year period from 1960 and a growth rate of 13.3 percent (see Figure 1). Louisiana added approximately 385,000 people to its

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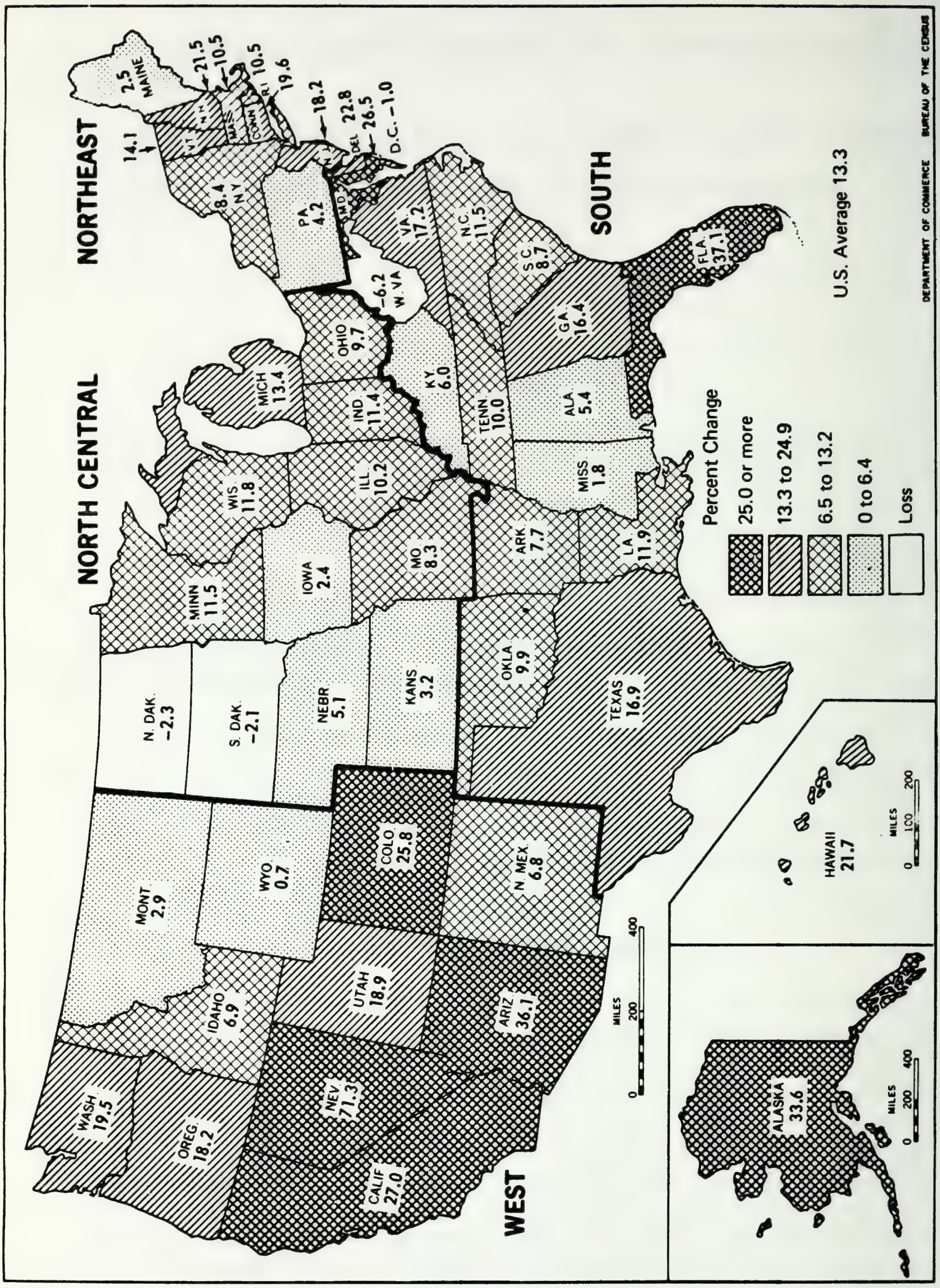
[1] This is the corrected population total for the state. Certain tables in this bulletin will show an uncorrected total. The difference is less than 2,000 people and not enough to account for significant effect on percentage distribution.


NORTHEAST
NORTH CENTRAL
SOUTH
WEST
MAINE 2.5
N.H. 21.5
VT. 14.1
MASS. 10.5
CONN. 19.6
R.I. 10.5
N.Y. 8.4
N.J. 18.2
PA. 4.2
DEL. 22.8
MD. 26.5
D.C. −1.0
VA. 17.2
W. VA. −6.2
N.C. 11.5
S.C. 8.7
GA. 16.4
FLA. 37.1
OHIO 9.7
MICH. 13.4
IND. 11.4
ILL. 10.2
WIS. 11.8
MINN. 11.5
IOWA 2.4
MO. 8.3
KY. 6.0
TENN. 10.0
ALA. 5.4
MISS. 1.8
ARK. 7.7
LA. 11.9
N. DAK. −2.3
S. DAK. −2.1
NEBR. 5.1
KANS. 3.2
OKLA. 9.9
TEXAS 16.9
MONT. 2.9
WYO. 0.7
COLO. 25.8
N. MEX. 6.8
IDAHO 6.9
UTAH 18.9
ARIZ. 36.1
WASH. 19.5
OREG. 18.2
NEV. 71.3
CALIF. 27.0
ALASKA 33.6
HAWAII 21.7
MILES 0 200 400
MILES 0 100 200
Percent Change
25.0 or more
13.3 to 24.9
6.5 to 13.2
0 to 6.4
Loss
U.S. Average 13.3
DEPARTMENT OF COMMERCE BUREAU OF THE CENSUS

population in this period to register a growth rate of 11.8 percent.[2] Both the nation and the state failed to grow as rapidly in the decade of the 60's as they had in the decade of the 50's. It may be a matter of some concern that the growth rate of the state dropped below the average for the nation from 1960 to 1970, whereas it had exceeded the average national growth from 1950 to 1960.

The relative drop in the growth rate of Louisiana is reflected in the fact that 20 states experienced a higher percentage increase in population from 1960-1970. In the preceding decade only 16 states had larger growth rates. In the Southern region, if Maryland is excluded, Louisiana ranked fifth in rate of growth, behind Florida (37.1 percent), Texas (16.9 percent), Georgia (16.4 percent), and Virginia (17.2 percent). Since Louisiana was the third fastest growing state in the region in the 1950's, its drop in relative growth will no doubt be a matter of some interest to planners. The percentage change in population for each state in the nation is shown in Figure 1.

Table 1 was prepared to show the historical growth pattern which has characterized Louisiana since 1810. The fact that stands out, in a scrutiny of this table, is that there were only two other 10-year periods when the state failed to grow at a higher rate than in the last decade.

TABLE 1.—Louisiana Population Growth, by Residence, 1810-1970

Year	The State		Urban		Rural	
	Total population	Percent increase over previous census	Population	Percent of total population	Population	Percent of total population
1970	3,643,180	11.8	2,406,150	66.1	21,235,156	33.9
1960	3,257,022	21.4	2,060,606	63.3	1,196,416	36.7
1950	2,683,516	13.5	1,379,998	51.4	1,303,518	48.6
1940	2,363,880	12.5	980,439	41.5	1,383,441	58.5
1930	2,101,593	16.9	833,532	39.7	1,268,061	60.3
1920	1,798,509	8.6	628,163	34.9	1,170,346	65.1
1910	1,656,388	19.9	496,516	30.0	1,159,872	70.0
1900	1,381,625	23.5	366,288	26.5	1,015,337	73.5
1890	1,118,588	19.0	283,845	25.4	834,743	74.6
1880	939,946	29.3	239,390	25.5	700,556	74.5
1870	726,915	2.7	202,523	27.9	524,392	72.1
1860	708,002	36.7	185,026	26.1	522,976	73.9
1850	517,762	46.9	134,470	26.0	383,292	74.0
1840	352,411	63.4	105,400	29.9	247,011	70.1
1830	215,739	40.6	46,082	21.4	169,657	78.6
1820	153,407	100.4	27,176	17.7	126,231	82.3
1810	76,556	....	17,242	22.5	59,314	77.5

---

[2] The growth rate of Louisiana is shown as 11.9 percent in Figure 1. This discrepancy is accounted for by the fact that this map was prepared before final counts were made.

There is always an interest in comparing the population size and growth rate of the state with its closest neighbors'. Census counts show that Texas continues to grow at a rate well above the national average and considerably faster than Louisiana (16.9 percent). Texas had 11,196,730 inhabitants in 1970 and ranked as the fourth largest state in the U.S. Both Mississippi and Arkansas failed to register population growth during the decade of the 1950's. It is thus significant that Arkansas increased its population by 7.7 percent and Mississippi by 1.8 percent in the last decade. Both states continue to lag behind Louisiana in total population, however, with 1,923,295 people living in Arkansas and 2,216,912 people living in Mississippi in 1970. The population of Texas is larger than that of the three states of Louisiana, Arkansas and Mississippi combined.

Population Growth, by Parish

A look at the population growth rate of the individual parishes within Louisiana indicates that some 44 of the 64 parishes increased in population between 1960 and 1970. Nineteen of these parishes grew at rates which exceeded the rate of increase of the national population as a whole. High rates of growth were characteristic of parishes in southeast Louisiana, and were also associated with metropolitan centers, although this pattern is not as clear-cut as it was from 1950 to 1960. These patterns will be described in the discussion which follows.

Vernon Parish had the largest rate of growth among all the parishes, a phenomenal 193.9 percent. This unusual growth is accounted for by the reactivation of Fort Polk, which is located in this parish. Table 2 shows the parishes of the state according to percentage change in population from 1960 to 1970 and 1950 to 1960. It is most enlightening to compare how the growth rate of the parishes changed from one decade to the other.

TABLE 2.—Population and Percent Change of the Parishes in Louisiana, 1950-1970

Parish	Population 1970	Population 1960	Population 1950	Change 1950-60	Change 1960-70
Acadia	52,109	49,931	47,050	6.1	4.4
Allen	20,794	19,867	18,835	5.5	4.7
Ascension	37,086	27,927	22,387	24.7	32.8
Assumption	19,654	17,991	17,278	4.1	9.2
Avoyelles	37,751	37,606	38,031	–1.1	.4
Beauregard	22,888	19,191	17,766	8.0	19.3
Bienville	16,024	16,726	19,105	–12.5	–4.2
Bossier	64,519	57,622	40,139	43.6	12.0
Caddo	230,184	223,859	176,547	26.8	2.8
Calcasieu	145,415	145,475	89,635	62.3	–.0
Caldwell	9,354	9,004	10,293	–12.5	3.9
Cameron	8,194	6,909	6,244	10.7	18.6
Catahoula	11,769	11,421	11,834	–3.5	3.0

(Continued)

TABLE 2.—(Continued)

Parish	Population 1970	Population 1960	Population 1950	Change 1950-60	Change 1960-70
Claiborne	17,024	19,407	25,063	–22.6	–12.3
Concordia	22,578	20,467	14,398	42.2	10.3
De Soto	22,764	24,248	24,398	–.6	–6.1
East Baton Rouge	285,167	230,058	158,236	45.4	24.0
East Carroll	12,884	14,433	16,302	–11.5	–10.7
East Feliciana	17,657	20,198	19,133	5.6	–12.6
Evangeline	31,932	31,639	31,629	.0	.9
Franklin	23,946	26,088	29,376	–11.2	–8.2
Grant	13,671	13,330	14,263	–6.5	2.6
Iberia	57,397	51,657	40,059	29.0	11.1
Iberville	30,746	29,939	26,750	11.9	2.7
Jackson	15,963	15,828	15,434	2.6	.9
Jefferson	337,568	208,769	103,873	101.0	61.7
Jefferson Davis	29,554	29,825	26,298	13.4	–.9
Lafayette	109,716	84,656	57,743	46.6	29.6
Lafourche	68,941	55,381	42,209	31.2	24.5
La Salle	13,295	13,011	12,717	2.3	2.2
Lincoln	33,800	28,535	25,782	10.7	18.5
Livingston	36,511	26,974	20,054	34.5	35.4
Madison	15,065	16,444	17,451	–5.8	–8.4
Morehouse	32,463	33,709	32,038	5.2	–3.7
Natchitoches	35,219	35,653	38,144	–6.5	–1.2
Orleans	593,471	627,525	570,445	10.0	–5.4
Ouachita	115,387	101,663	74,713	36.1	13.5
Plaquemines	25,225	22,545	14,239	58.3	11.9
Pointe Coupee	22,002	22,488	21,841	3.0	–2.2
Rapides	118,078	111,351	90,648	22.8	6.0
Red River	9,226	9,978	12,113	–17.6	–7.5
Richland	21,774	23,824	26,672	–10.7	–8.6
Sabine	18,638	18,564	20,880	–11.1	.4
St. Bernard	51,185	32,186	11,087	190.3	59.0
St. Charles	29,550	21,219	13,363	58.8	39.3
St. Helena	9,937	9,162	9,013	1.7	8.5
St. James	19,733	18,369	15,334	19.8	7.4
St. John the Baptist	23,813	18,439	14,861	24.1	29.1
St. Landry	80,364	81,493	78,476	3.8	–1.4
St. Martin	32,453	29,063	26,353	10.3	11.7
St. Mary	60,752	48,833	35,848	36.2	24.4
St. Tammany	63,585	38,643	26,988	43.2	64.5
Tangipahoa	65,875	59,434	53,218	11.7	10.8
Tensas	9,732	11,796	13,209	–10.7	–17.5
Terrebonne	76,049	60,771	43,328	40.3	25.1
Union	18,447	17,624	19,141	–7.9	4.7
Vermilion	43,071	38,855	36,929	5.2	10.9
Vernon	53,794	18,301	18,974	–3.5	193.9
Washington	41,987	44,015	38,371	14.7	–4.6
Webster	39,939	39,701	35,704	11.2	.6
West Baton Rouge	16,864	14,796	11,738	26.1	14.0
West Carroll	13,028	14,177	17,248	–17.8	–8.1
West Feliciana	11,376	12,395	10,169	21.9	–8.2
Winn	16,369	16,034	16,119	–.5	2.1

The 20 parishes which lost people in the last decade are shown in Figures 2 and 3. Figure 2 shows the change in population size of the parishes, while Figure 3 shows the percentage change in population. A study of this map shows that the upper Louisiana-Mississippi delta area has the largest number of parishes suffering population decreases. It is of note that only four parishes showed losses of 10 percent or more and that two parishes with losses included large total populations — Orleans and St. Landry.

At this point, it is of interest to review the components of population change for the various parishes. These components—births, deaths and net migration—are shown in Table 3. A study of Table 3 shows that every parish had more births than deaths from 1960 to 1970. However, 20 parishes suffered sufficient outmigration to offset the natural increase experienced in the parish.

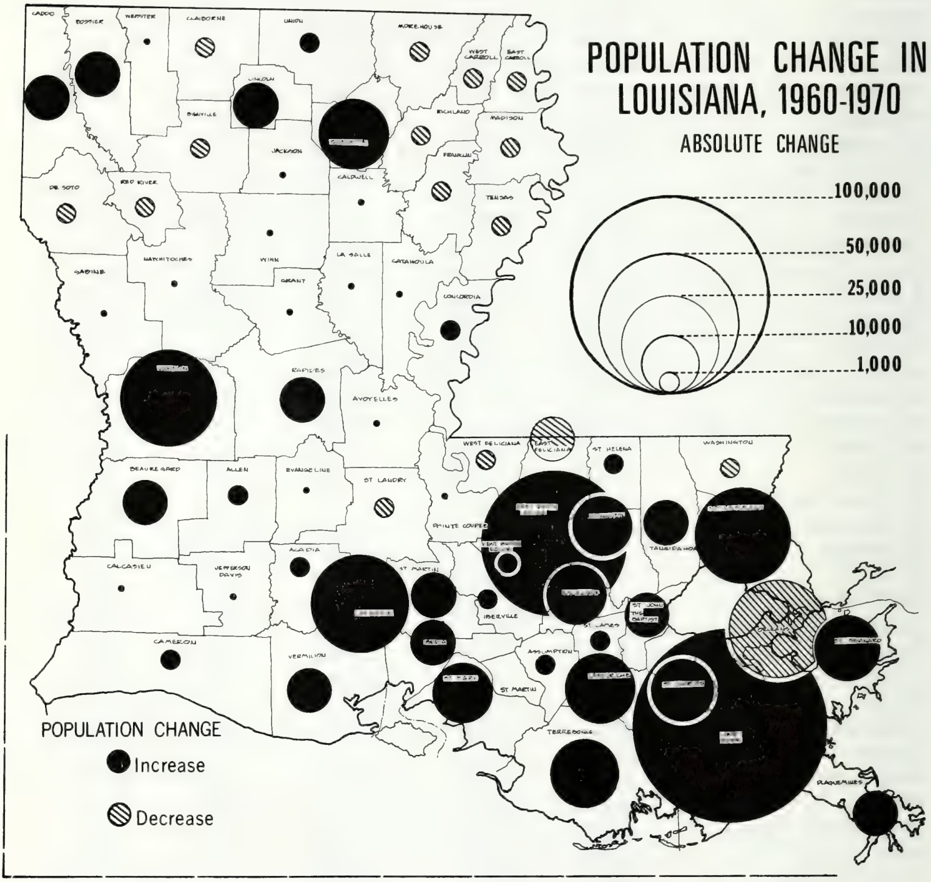


FIGURE 2

Altogether, the state lost a net 132,117 persons through migration to outside places from 1960 to 1970. A breakdown by race of this outmigration reveals that blacks are continuing to leave the state, whereas more whites are entering the state than are leaving. A total of 157,973 more blacks moved out of the state than moved in during the decade, but 25,856 more whites moved in than moved out. It can be seen in Table 3 that two large parishes, Orleans and St. Landry, had substantial outmigration, a pattern which may be indicative of important reversals in past trends.

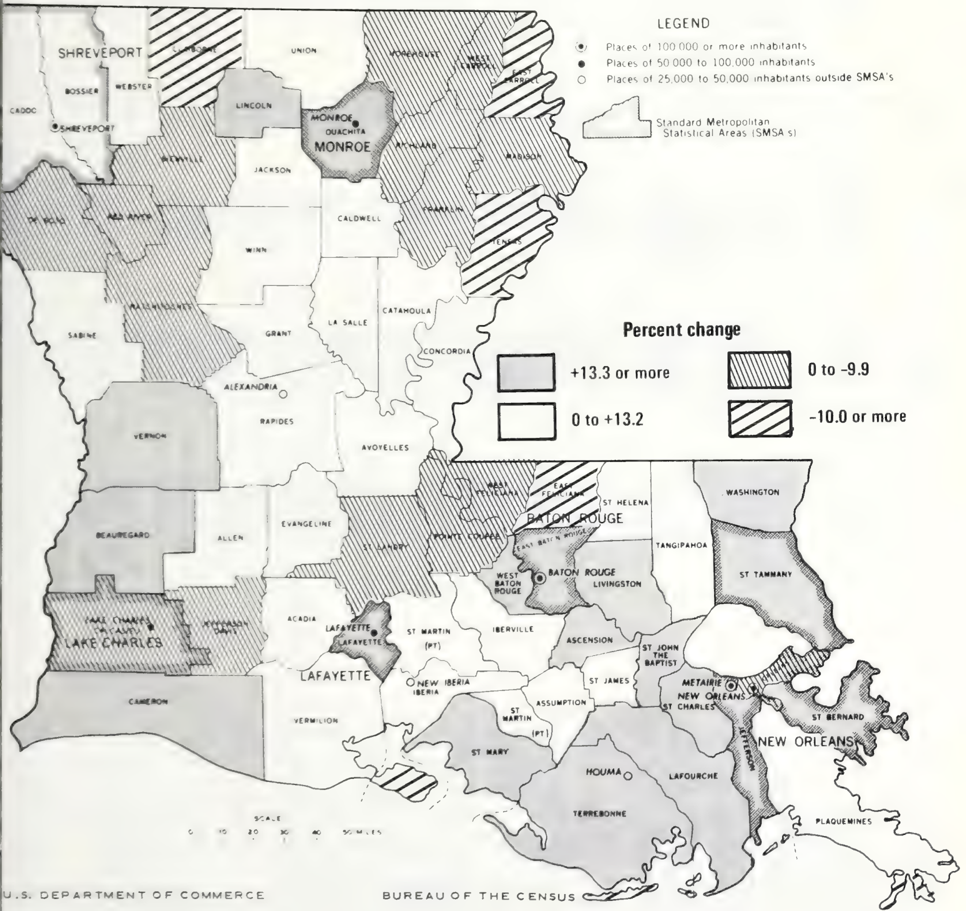


FIGURE 3.–Population Change for Parishes, 1960-1970.

TABLE 3.—Components of Population Change, by Race, 1970 and 1960

The State					Components of change			
	Population		Change				Net migration	
Parishes	1970	1960	Number	Percent	Births	Deaths	Number	Percent
THE STATE								
Total population	3,641,306	3,257,022	384,284	11.8	832,462	316,061	–132,117	–4.1
White	2,539,547	2,111,715	327,832	14.8	501,173	199,197	25,856	1.2
Negro and other races	1,101,759	1,045,307	56,452	5.4	331,289	116,864	–157,973	–15.1
Metropolitan residence	1,996,197	1,750,456	245,741	14.0	441,118	167,113	–28,264	–1.6
Inside central cities	1,144,778	1,100,327	44,451	4.0	267,334	119,851	–103,032	–9.4
Outside central cities	851,419	650,129	201,290	31.0	173,784	47,262	74,768	11.5
Nonmetropolitan residence	1,645,109	1,506,566	138,543	9.2	391,344	148,948	–103,853	–6.9
PARISHES								
Acadia	52,109	49,931	2,178	4.4	13,084	4,650	–6,256	–12.5
Negro and other races	10,348	9,827	521	5.3	3,600	1,106	–1,973	–20.1
Allen	20,794	19,867	927	4.7	4,888	2,027	–1,934	–9.7
Negro and other races	5,007	4,933	74	1.5	1,419	574	–771	–15.6
Ascension	37,086	27,927	9,159	32.8	8,246	2,699	3,612	12.9
Negro and other races	9,952	8,914	1,038	11.6	2,880	1,145	–697	–7.8
Assumption	19,654	17,991	1,663	9.2	5,015	1,795	–1,557	–8.7
Negro and other races	7,333	7,418	–85	–1.1	2,319	869	–1,535	–20.7
Avoyelles	37,751	37,606	145	0.4	8,841	4,149	–4,547	–12.1
Negro and other races	10,501	10,472	29	0.3	3,747	1,189	–2,529	–24.2
Beauregard	22,888	19,191	3,697	19.3	4,703	2,170	1,164	6.1
Negro and other races	4,292	4,305	–13	–0.3	1,403	518	–898	–20.9
Bienville	16,024	16,726	–702	–4.2	3,340	2,059	–1,983	–11.9
Negro and other races	7,536	8,256	–720	–8.7	2,143	861	–2,002	–24.2
Bossier	64,519	57,622	6,897	12.0	14,954	3,805	–4,252	–7.4
Negro and other races	12,932	14,346	–1,414	–9.9	4,133	1,454	–4,093	–28.5
Caddo	230,184	223,859	6,325	2.8	51,236	21,585	–23,326	–10.4
Negro and other races	84,448	81,656	2,802	3.4	24,391	9,277	–12,322	–15.1
Calcasieu	145,415	145,475	–60	–	34,936	10,291	–24,705	–17.0
Negro and other races	32,196	30,375	1,821	6.0	9,577	2,878	–4,878	–16.1
Caldwell	9,354	9,004	350	3.9	1,799	1,108	–341	–3.8
Negro and other races	2,491	2,505	–14	–0.6	559	257	–316	–12.6
Cameron	8,194	6,909	1,285	18.6	1,578	480	187	2.7
Catahoula	11,769	11,421	348	3.0	2,828	1,170	–1,310	–11.5
Negro and other races	3,590	4,016	–426	–10.6	1,282	458	–1,250	–31.1

(Continued)

Parishes	Population		Change		Components of change			
							Net migration	
	1970	1960	Number	Percent	Births	Deaths	Number	Percent
PARISHES–Continued								
Claiborne	17,024	19,407	–2,383	–12.3	3,439	2,263	–3,559	–18.2
Negro and other races	8,513	9,761	–1,248	–12.8	2,384	1,082	–2,550	–26.1
Concordia	22,578	20,467	2,111	10.3	6,076	2,121	–1,844	–9.0
Negro and other races	8,771	9,474	–703	–7.4	2,910	1,242	–2,371	–25.0
De Soto	22,764	24,248	–1,484	–6.1	5,377	2,945	–3,916	–16.1
Negro and other races	12,128	13,954	–1,826	–13.1	3,750	1,609	–3,967	–28.4
East Baton Rouge	285,167	230,058	55,109	24.0	59,532	17,830	13,407	5.8
Negro and other races	82,285	73,163	9,122	12.5	21,264	7,550	–4,592	–6.3
East Carroll	12,884	14,433	–1,549	–10.7	3,957	1,716	–3,790	–26.3
Negro and other races	7,626	8,831	–1,205	–13.6	2,697	1,210	–2,692	–30.5
East Feliciana	17,657	20,198	–2,541	–12.6	4,043	1,740	–4,844	–24.0
Negro and other races	9,385	10,914	–1,529	–14.0	2,882	1,007	–3,404	–31.2
Evangeline	31,932	31,639	293	0.9	9,575	3,288	–5,994	–18.9
Negro and other races	8,687	8,481	206	2.4	4,225	783	–3,236	–38.2
Franklin	23,946	26,088	–2,142	–8.2	5,947	2,547	–5,542	–21.2
Negro and other races	8,596	10,591	–1,995	–18.8	3,172	993	–4,174	–39.4
Grant	13,671	13,330	341	2.6	2,895	1,533	–1,021	–7.7
Negro and other races	3,114	3,224	–110	–3.4	998	347	–761	–23.6
Iberia	57,397	51,657	5,740	11.1	15,808	4,637	–5,431	–10.5
Negro and other races	16,220	14,814	1,406	9.5	5,534	1,704	–2,424	–16.4
Iberville	30,746	29,939	807	2.7	8,015	3,307	–3,901	–13.0
Negro and other races	14,746	14,667	79	0.5	4,362	1,867	–2,416	–16.5
Jackson	15,963	15,828	135	0.9	3,271	1,734	–1,402	–8.9
Negro and other races	5,232	5,132	100	1.9	1,551	539	–911	–17.8
Jefferson	337,568	208,769	128,799	61.7	65,171	15,902	79,530	38.1
Negro and other races	43,011	31,924	11,087	34.7	11,563	3,089	2,613	8.2
Jefferson Davis	29,554	29,825	–271	–0.9	7,027	2,534	–4,764	–16.0
Negro and other races	6,345	6,334	11	0.2	1,889	625	–1,253	–19.8
Lafayette	109,716	84,656	25,060	29.6	24,963	6,528	6,625	7.8
Negro and other races	24,405	20,333	4,072	20.0	7,632	2,010	–1,550	–7.6
Lafourche	68,941	53,381	13,560	24.5	17,439	4,330	451	7.8
Negro and other races	7,900	6,762	1,138	16.8	3,080	814	–1,128	–16.7
LaSalle	13,295	13,011	284	2.2	2,808	1,368	–1,156	–8.9
Negro and other races	1,521	1,656	–135	–8.2	504	202	–437	–26.4

(Continued)

TABLE 3.–(Continued)

The State					Components of change			
	Population		Change				Net migration	
Parishes	1970	1960	Number	Percent	Births	Deaths	Number	Percent
PARISHES–Continued								
Lincoln	33,800	28,535	5,265	18.5	5,722	2,560	2,103	7.4
Negro and other races	13,616	11,941	1,675	14.0	2,881	1,014	–192	–1.6
Livingston	36,511	26,974	9,537	35.4	7,583	2,446	4,400	16.3
Negro and other races	4,388	4,053	335	8.3	1,587	377	–875	–21.6
Madison	15,065	16,444	–1,379	–8.4	4,159	2,093	–3,445	–20.9
Negro and other races	9,170	10,677	–1,507	–14.1	3,023	1,565	–2,965	–27.8
Morehouse	32,463	33,709	–1,246	–3.7	8,593	3,327	–6,512	–19.3
Negro and other races	13,797	15,798	–2,001	–12.7	5,063	1,746	–5,318	–33.7
Natchitoches	35,219	35,653	–434	–1.2	7,479	3,738	–4,175	–11.7
Negro and other races	13,151	15,571	–2,420	–15.5	3,887	1,828	–4,479	–28.8
Orleans	593,471	627,525	–34,054	–5.4	142,506	74,401	34,051	5.4
Negro and other races	269,986	234,931	35,055	14.9	73,997	28,394	–10,548	–4.5
Ouachita	115,387	101,663	13,724	13.5	27,046	9,716	–3,606	–3.5
Negro and other races	31,928	32,759	–831	–2.5	110,971	3,982	–7,820	–23.9
Plaquemines	25,225	22,545	2,680	11.9	6,841	1,608	–2,553	–2.1
Negro and other races	6,373	6,504	–131	–2.0	2,275	585	–1,821	–28.0
Pointe Coupee	22,002	22,488	–486	–2.2	6,532	2,263	–4,755	–21.1
Negro and other races	11,096	12,054	–958	–7.9	3,991	1,283	–3,666	–30.4
Rapides	118,078	111,351	6,727	6.0	25,364	10,777	–7,860	–7.1
Negro and other races	33,321	34,006	–685	–2.0	9,415	4,149	–5,951	–17.5
Red River	9,226	9,978	–752	–7.5	2,081	1,122	–1,711	–17.1
Negro and other races	3,895	4,746	–851	–17.9	1,123	415	–1,559	–32.9
Richland	21,774	23,824	–2,050	–8.6	6,123	2,524	–5,649	–23.7
Negro and other races	8,909	10,569	–1,660	–15.7	3,681	1,185	–4,156	–39.3
Sabine	18,638	18,564	74	0.4	4,282	2,178	–2,030	–10.9
Negro and other races	3,733	4,383	–650	–14.8	1,314	521	–1,443	–32.9
St. Bernard	51,185	32,186	18,999	59.0	9,107	2,376	12,268	38.1
St. Charles	29,550	21,219	8,331	39.3	6,679	1,671	3,323	15.7
Negro and other races	8,114	5,745	2,369	41.2	2,068	628	929	16.2
St. Helena	9,937	9,162	775	8.5	2,058	801	–482	–5.3
Negro and other races	5,637	5,086	551	10.8	1,520	404	–565	–11.1
St. James	19,733	18,369	1,364	7.4	5,495	1,819	–2,312	–12.6
Negro and other races	9,287	9,054	233	2.6	3,057	1,030	–1,794	–19.8

(Continued)

TABLE 3.–(Continued)

The State	Population		Change		Components of change			
							Net migration	
Parishes	1970	1960	Number	Percent	Births	Deaths	Number	Percent
PARISHES–Continued								
St. John the Baptist	23,813	18,439	5,374	29.1	5,786	1,810	1,398	7.6
Negro and other races	11,010	9,513	1,497	15.7	3,279	969	–813	–8.5
St. Landry	80,364	81,493	–1,129	–1.4	22,318	7,645	–15,802	–19.4
Negro and other races	33,257	35,050	–1,793	–5.1	11,688	3,583	–9,898	–28.2
St. Martin	32,453	29,063	3,390	11.7	8,137	2,493	–2,255	–7.8
Negro and other races	11,307	10,821	486	4.5	3,505	1,013	–2,006	–18.5
St. Mary	60,752	48,833	11,919	24.4	15,919	4,355	355	0.7
Negro and other races	17,386	15.078	2,308	14.6	5,064	1,850	–906	–6.0
St. Tammany	63,585	38,643	24,942	64.5	11,667	4,679	17,954	46.5
Negro and other races	12,384	10,612	1,772	16.7	3,399	1,181	–446	–4.2
Tangipahoa	65,875	59,434	6,441	10.8	16,449	6,812	–3,196	–5.4
Negro and other races	21,007	20,119	888	4.4	7,374	2,511	–3,975	–19.8
Tensas	9,732	11,796	–2,064	–17.5	2,659	1,319	–3,404	–28.9
Negro and other races	5,800	7,668	–1,868	–24.4	1,926	923	–2,871	–37.4
Terrebonne	76,049	60,771	15,278	25.1	21,073	4,767	–1,028	–1.7
Negro and other races	13,611	12,443	1,168	9.4	4,813	1,345	–2,300	–18.5
Union	18,447	17,624	823	4.7	4,165	2,024	–1,318	–7.5
Negro and other races	6,225	6,485	–260	–4.0	2,173	633	–1,800	–27.8
Vermilion	43,071	38,855	4,216	10.9	9,887	3,513	–2,158	–5.6
Negro and other races	5,976	5,019	957	19.1	1,885	512	–416	–8.3
Vernon	53,794	18,301	35,493	193.9	5,040	2,516	32,969	180.1
Negro and other races	6,277	2,443	3,834	156.9	914	388	3,308	135.4
Washington	41,987	44,015	–2,028	–4.6	9,452	4,638	–6,842	–15.5
Negro and other races	13,714	14,908	–1,194	–8.0	4,027	1,642	–1,194	–8.0
Webster	39,939	39,701	238	0.6	8,270	4,020	–4,012	–10.1
Negro and other races	12,480	13,695	–1,215	–8.9	3,730	1,544	–3,401	–24.8
West Baton Rouge	16,864	14,796	2,068	14.0	4,756	1,448	–1,240	–8.4
Negro and other races	7,232	7,294	–62	–0.9	2,570	922	–1,710	–23.4
West Carroll	13,028	14,177	–1,149	–8.1	3,300	1,475	–2,974	–21.0
Negro and other races	2,536	3,179	–643	–20.2	1,182	380	–1,445	–45.5
West Feliciana	11,376	12,395	–1,019	–8.2	2,012	834	–2,197	–17.7
Negro and other races	7,536	8,198	–662	–8.1	1,505	607	–1,560	–19.0
Winn	16,369	16,034	335	2.1	3,131	1,982	–814	–5.1
Negro and other races	4,983	5,003	–2.0	–0.4	1,353	584	–789	–15.8

Distribution of the Population

The varying rates of population change from 1960 to 1970 in Louisiana give rise to a new pattern of population distribution, which is graphically shown in Figure 4. It may come as a surprise to some to learn that over three-fourths of the state's population is now located in the area from Alexandria south. This increased predominance of population in Louisiana's southern region reflects the continued growth of the major population centers, including the New Orleans, Baton Rouge, Lafayette and Lake Charles areas. With the exception of the Shreveport and Monroe areas, North Louisiana does not include centers of relatively large population concentration.

Nearly one-third of the people of Louisiana still live in the metropolitan cities of the state. In 1960 Louisiana had five cities of over 50,000, but the 1970 Census indicates that the growth of Lafayette has raised the number of such centers to six. It can be seen in Table 4

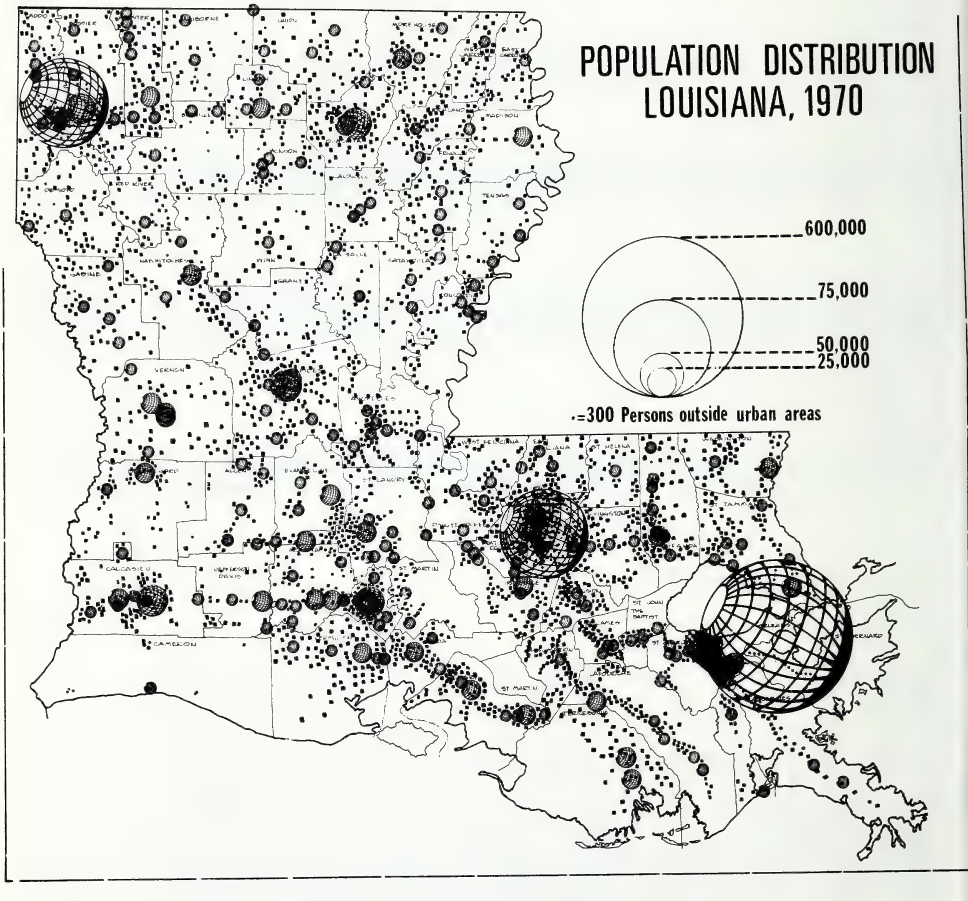


FIGURE 4

that New Orleans had 593,471 people in 1970, Shreveport 182,064, Baton Rouge 165,963, Lake Charles 77,998, Lafayette 68,908 and Monroe 59,374. It is worthy of note that Lafayette has replaced Monroe as the state's fifth largest city.

The proportion of the state's population living in the six major cities did not change very much in the last decade, with the growth of Lafayette offset by the decline in the number of persons living in New Orleans and lack of significant growth in the other major cities. The striking change in population distribution, therefore, is the greater concentration of people in smaller urban centers, and within metropolitan areas but outside the major cities. This suburbanization of the urban population is especially notable in the New Orleans area, with the phenomenal growth of the suburban parishes of Jefferson, St. Bernard and St. Tammany. About one out of every two persons in Louisiana lives in the eight parishes making up the six metropolitan areas in the state. This picture compares with a national average of two out of three persons living in metropolitan centers.

TABLE 4.—Incorporated Places in Louisiana Ranked by Size in 1970 and 1960

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
1	1	New Orleans	593,471	627,525
2	2	Shreveport	182,064	164,372
3	3	Baton Rouge	165,963	152,419
4	4	Lake Charles	77,998	63,392
5	6	Lafayette	68,908	40,400
6	5	Monroe	59,374	52,219
7	8	Bossier City	41,595	32,776
8	7	Alexandria	41,557	40,279
9	10	Houma	30,922	22,561
10	9	New Iberia	30,147	29,062
11	14	Kenner	29,858	17,037
12	11	Gretna	24,875	21,967
13	13	Opelousas	20,121	17,417
14	12	Bogalusa	18,412	21,423
15	18	Ruston	17,365	13,991
16	20	Morgan City	16,586	13,540
17	15	Crowley	16,104	15,617
18	42	Slidell	16,101	6,356
19	19	Natchitoches	15,974	13,924
20	21	Thibodaux	14,925	13,403
21	16	West Monroe	14,868	15,215
22	17	Bastrop	14,713	15,193
23	22	Minden	13,996	12,785
24	24	Sulphur	13,551	11,429
25	30	Harahan	13,037	9,275
26	26	Hammond	12,487	10,563
27	23	Jennings	11,783	11,887
28	28	Westwego	11,402	9,815
29	25	Eunice	11,390	11,326

(Continued)

TABLE 4.—(Continued)

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
30	27	Abbeville	10,996	10,414
31	35	Ville Platte	9,692	7,512
32	29	Tallulah	9,643	9,413
33	33	Rayne	9,510	8,634
34	31	Franklin	9,325	8,673
35	32	Pineville	8,951	8,636
36	53	Leesville	8,928	4,689
37	51	Baker	8,281	4,823
38	36	De Ridder	8,030	7,188
39	34	Plaquemine	7,739	7,689
40	43	Donaldsonville	7,367	6,082
41	39	Oakdale	7,301	6,618
42	38	Covington	7,170	6,754
43	40	St. Martinville	7,153	6,468
44	37	Winnfield	7,142	7,022
45	44	Denham Springs	6,752	5,991
46	41	Springhill	6,496	6,437
47	45	Mansfield	6,432	5,839
48	47	Jeanerette	6,322	5,568
49	46	Lake Providence	6,183	5,781
50	50	Port Allen	5,728	5,026
51	48	Kaplan	5,540	5,267
52	57	Vidalia	5,538	4,313
53	49	Bunkie	5,395	5,188
54	56	Winnsboro	5,349	4,437
55	55	Ferriday	5,239	4,563
56	63	Jonesboro	5,072	3,848
57	71	Zachary	4,964	3,268
58	69	Breaux Bridge	4,942	3,303
59	104	Jackson	4,697	1,824
60	52	Ponchatoula	4,545	4,727
61	58	Marksville	4,519	4,257
62	72	Gonzales	4,512	3,252
63	54	Homer	4,483	4,665
64	80	Patterson	4,409	2,923
65	74	Grambling	4,407	3,144
66	62	Berwick	4,168	3,880
67	68	Westlake	4,082	3,311
68	82	Vivian	4,046	2,624
69	59	Rayville	3,962	4,052
70	60	New Roads	3,945	3,965
71	64	Church Point	3,865	3,606
72	67	Amite City	3,593	3,316
73	75	Franklinton	3,562	3,141
74	65	Lake Arthur	3,551	3,541
75	78	Vinton	3,454	2,987
76	61	De Quincy	3,448	3,928
77	81	Farmerville	3,416	2,727
78	79	Mamou	3,275	2,928
79	70	Lutcher	3,274	3,274

(Continued)

TABLE 4.—(Continued)

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
80	66	Welsh	3,203	3,332
81	73	Many	3,112	3,164
82	77	Haynesville	3,055	3,031
83	84	Arcadia	2,970	2,547
84	85	Delhi	2,887	2,514
85	86	Jonesville	2,761	2,347
86	83	Kentwood	2,736	2,607
87	76	Golden Meadow	2,681	3,097
88	94	Gramercy	2,567	2,094
89	93	Jena	2,389	2,098
90	87	Kinder	2,307	2,299
91	118	Carencro	2,302	1,519
92	107	Mandeville	2,282	1,740
93	95	Grand Isle	2,236	2,074
94	88	White Castle	2,206	2,253
95	127	Zwolle	2,169	1,326
96	101	Port Barre	2,133	1,876
97	117	Baldwin	2,117	1,548
98	125	Plain Dealing	2,116	1,357
99	98	Melville	2,076	1,939
100	92	Simmesport	2,027	2,125
101	96	Erath	2,024	2,019
102	89	Lockport	1,995	2,221
103	91	Gueydan	1,984	2,156
104	105	Oak Grove	1,980	1,797
105	103	Delcambre	1,975	1,857
106	90	Cullen	1,956	2,194
107	99	Colfax	1,892	1,934
108	116	Clinton	1,884	1,568
109	110	St. Joseph	1,864	1,653
110	102	Iowa	1,857	1,857
111	106	Oberlin	1,857	1,794
112	114	Cottonport	1,846	1,581
113	111	Bernice	1,794	1,641
114	100	Basile	1,779	1,932
115	97	Independence	1,770	1,941
116	152	Ringgold	1,731	953
117	112	Broussard	1,707	1,600
118	115	Mansura	1,699	1,579
119	128	Sunset	1,675	1,307
120	135	Arnaudville	1,673	1,184
121	121	Glenmora	1,651	1,447
122	109	St. Francisville	1,603	1,661
123	113	Elton	1,598	1,595
124	119	Lecompte	1,518	1,485
125	126	Benton	1,493	1,336
126	108	Coushatta	1,492	1,663
127	129	Washington	1,473	1,291
128	123	Waterproof	1,438	1,412
129	145	Krotz Springs	1,435	1,057

(Continued)

TABLE 4.—(Continued)

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
130	120	Newellton	1,403	1,453
131	136	Livingston	1,398	1,183
132	132	Olla	1,387	1,246
133	140	Gibsland	1,380	1,150
134	137	Maringouin	1,365	1,168
135	156	Walker	1,363	912
136	151	Pearl River	1,361	964
137	130	Wisner	1,339	1,254
138	158	Scott	1,334	902
139	124	Logansport	1,330	1,371
140	138	Grand Coteau	1,301	1,165
141	134	Merryville	1,286	1,232
142	188	Brusly Landing	1,282	544
143	131	Roseland	1,273	1,254
144	133	Iota	1,271	1,245
145	142	Cotton Valley	1,261	1,145
146	143	Boyce	1,240	1,094
147	148	Duson	1,199	1,033
148	139	Sorrento	1,182	1,151
149	0	Sterlington	1,118	0
150	159	Clayton	1,103	882
151	150	Dubach	1,096	1,013
152	147	Cheneyville	1,082	1,037
153	146	Campti	1,078	1,045
154	0	Ridgecrest	1,076	0
155	141	Napoleonville	1,008	1,148
156	153	Youngsville	1,002	946
157	149	Columbia	1,000	1,021
158	161	Montgomery	923	866
159	122	Oil City	907	1,430
160	154	Clarks	889	940
161	180	Haughton	885	611
162	169	Sarepta	882	737
163	181	Sibley	869	595
164	176	Abita Springs	839	655
165	155	Morganza	836	937
166	162	Mooringsport	830	864
167	168	Chatham	827	758
168	157	Pleasant Hill	826	907
169	164	Mer Rouge	819	853
170	160	Hodge	818	878
171	165	Moreauville	807	815
172	163	Madisonville	801	860
173	171	Marion	796	685
174	172	Morse	759	682
175	170	Mermentau	756	716
176	195	Gilbert	746	472
177	177	Junction City	733	639
178	175	Loreauville	728	655
179	184	Addis	724	590

(Continued)

TABLE 4.—(Continued)

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
180	144	Doyline	716	1,061
181	166	Grosse Tete	710	768
182	187	Albany	700	557
183	178	Estherwood	661	639
184	191	Greensburg	652	512
185	173	North Hodge	640	680
186	194	Florien	639	496
187	167	Sicily Island	630	761
188	183	Harrisonburg	626	594
189	174	Rosedale	621	674
190	199	Livonia	611	430
191	0	Wilson	606	0
192	182	Tullos	600	594
193	204	Rosepine	587	414
194	209	Slaughter	580	403
195	196	Choudrant	555	465
196	190	Mangham	544	521
197	185	Bonita	533	574
198	186	Provencal	530	570
199	212	Hornbeck	525	374
200	202	Grayson	516	428
201	211	Pine Prairie	515	387
202	189	Leonville	512	526
203	0	Elizabeth	504	0
204	205	Parks	491	413
205	0	Simpson	491	0
206	0	Fordoche	488	0
207	207	Maurice	476	411
208	197	Tangipahoa	469	465
209	192	Dodson	457	512
210	210	Dixie Inn	456	399
211	198	Hessmer	454	433
212	232	Clarence	448	286
213	206	Epps	448	411
214	179	South Mansfield	439	616
215	0	Hosston	428	0
216	214	Simsboro	412	363
217	223	Woodworth	409	320
218	201	Fenton	404	429
219	193	Collinston	397	497
220	217	Port Vincent	387	340
221	208	Athens	387	406
222	229	Converse	375	291
223	0	Ida	370	0
224	227	Forest Hill	370	302
225	243	Kilbourne	370	227
226	224	Tickfaw	370	317
227	215	Dry Prong	352	360
228	203	Norwood	348	427
229	213	Pollock	341	366

(Continued)

TABLE 4.—(Continued)

Rank 1970	Rank 1960	Name	Population 1970	Population 1960
230	228	Goldonna	337	292
231	216	Keatchie	328	345
232	218	Varnado	320	331
233	235	Angie	317	254
234	230	Heflin	314	289
235	200	Palmetto	312	430
236	219	Saline	307	329
237	220	Evergreen	307	325
238	222	Georgetown	306	321
239	245	Sun	288	224
240	226	Bienville	287	305
241	240	Calvin	286	232
242	221	Grand Cane	284	322
243	234	Turkey Creek	280	279
244	0	Powhatan	277	0
245	231	Oak Ridge	276	287
246	225	Robeline	274	308
247	0	Rodessa	273	0
248	0	Springfield	268	0
249	0	Cankton	260	0
250	244	Folsom	249	225
251	239	Sikes	237	233
252	242	Plaucheville	224	228
253	0	Forest	221	0
254	0	McNary	220	0
255	251	Reeves	214	151
256	236	Dubberly	212	249
257	0	Greenwood	212	0
258	0	Gilliam	211	0
259	0	Ashland	211	0
260	247	Montpelier	211	197
261	246	Noble	209	206
262	0	Edgefield	201	0
263	0	Spearsville	197	0
264	0	Hall Summit	190	0
265	0	Corbin	189	0
266	250	Pioneer	188	154
267	233	Longstreet	182	283
268	252	Castor	178	142
269	237	Baskin	177	238
270	0	Shongaloo	173	0
271	248	Quitman	169	185
272	249	Eros	164	176
273	0	Lillie	160	0
274	0	Jamestown	153	0
275	253	Delta	153	111
276	241	Lisbon	151	229
277	238	Stanley	145	234
278	0	Mount Lebanon	102	0
279	254	Mound	78	107
280	255	Bryceland	65	89

As shown in Table 5, the eight parishes with the largest populations are: Orleans 593,471, Jefferson 337,568, East Baton Rouge 285,167, Caddo 230,184, Calcasieu 145,415, Rapides 118,078, Ouachita 115,387 and Lafayette 109,716. With the exception of Rapides all of the larger parishes are part of metropolitan areas as designated by the U.S. Census. The New Orleans area also includes St. Bernard with 51,185 people and St. Tammany with 63,585, besides Orleans and Jefferson Parishes, and the Shreveport area includes Bossier Parish with 64,519 besides Caddo Parish.

TABLE 5.—Parishes of Louisiana Ranked by Size in 1970 and 1960

Rank 1970	Rank 1960	Parish	Population 1970	Population 1960
1	1	Orleans	593,471	627,525
2	4	Jefferson	337,568	208,769
3	2	East Baton Rouge	285,167	230,058
4	3	Caddo	230,184	223,859
5	5	Calcasieu	145,415	145,475
6	6	Rapides	118,078	111,351
7	7	Ouachita	115,387	101,663
8	8	Lafayette	109,716	84,656
9	9	St. Landry	80,364	81,493
10	10	Terrebonne	76,049	60,771
11	13	Lafourche	68,941	55,381
12	11	Tangipahoa	65,875	59,434
13	12	Bossier	64,519	57,622
14	20	St. Tammany	63,585	38,643
15	16	St. Mary	60,752	48,833
16	14	Iberia	57,397	51,657
17	46	Vernon	53,794	18,301
18	15	Acadia	52,109	49,931
19	24	St. Bernard	51,185	32,186
20	19	Vermilion	43,071	38,855
21	17	Washington	41,987	44,015
22	18	Webster	39,939	39,701
23	21	Avoyelles	37,751	37,606
24	30	Ascension	37,086	27,927
25	31	Livingston	36,511	26,974
26	22	Natchitoches	35,219	35,653
27	29	Lincoln	33,800	28,535
28	23	Morehouse	32,463	33,709
29	28	St. Martin	32,453	29,063
30	25	Evangeline	31,932	31,639
31	26	Iberville	30,746	29,939
32	27	Jefferson Davis	29,554	29,825
33	37	St. Charles	29,550	21,219
34	35	Plaquemines	25,225	22,545
35	32	Franklin	23,946	26,088
36	44	St. John the Baptist	23,813	18,439

(Continued)

TABLE 5.—(Continued)

Rank 1970	Rank 1960	Parish	Population 1970	Population 1960
37	42	Beauregard	22,888	19,191
38	33	De Soto	22,764	24,248
39	38	Concordia	22,578	20,467
40	36	Pointe Coupee	22,002	22,488
41	34	Richland	21,774	23,824
42	40	Allen	20,794	19,867
43	45	St. James	19,733	18,369
44	47	Assumption	19,654	17,991
45	43	Sabine	18,638	18,564
46	48	Union	18,447	17,624
47	39	East Feliciana	17,657	20,198
48	41	Claiborne	17,024	19,407
49	53	West Baton Rouge	16,864	14,796
50	51	Winn	16,369	16,034
51	49	Bienville	16,024	16,726
52	52	Jackson	15,963	15,828
53	50	Madison	15,065	16,444
54	56	Grant	13,671	13,330
55	57	La Salle	13,295	13,011
56	55	West Carroll	13,028	14,177
57	54	East Carroll	12,884	14,433
58	60	Catahoula	11,769	11,421
59	58	West Feliciana	11,376	12,395
60	62	St. Helena	9,937	9,162
61	59	Tensas	9,732	11,796
62	63	Caldwell	9,354	9,004
63	61	Red River	9,226	9,978
64	64	Cameron	8,194	6,909

The population of all incorporated places is shown in Tables 4 and 6. In Table 6 the population change in these places from 1960 to 1970 is shown by parish. Table 4 is included simply for the person interested in the rank order by size of the various incorporated centers in the state. This table should be contemplated in conjunction with Table 7, which shows the unincorporated population centers including 1,000 or more people. Such a comparison will indicate that several population centers which remain unincorporated are of relatively large size.

TABLE 6.—Percent Change of Incorporated Places in Louisiana, Arranged by Parishes, 1950-1970

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
ACADIA	52,109	49,931	4.4	47,050	6.1
Church Point	3,865	3,606	7.2	2,897	24.5
Crowley	16,104	15,617	3.1	12,784	22.2
Estherwood	661	639	3.4	547	16.8
Iota	1,271	1,245	2.1	1,162	7.1
Mermentau	756	716	5.6	636	12.6
Morse	759	682	11.3	679	.4
Rayne	9,510	8,634	10.1	6,485	33.1
ALLEN	20,794	19,867	4.7	18,835	5.5
Elizabeth	504	0	.0	0	.0
Kinder	2,307	2,299	.3	2,003	14.8
Oakdale	7,301	6,618	10.3	5,598	18.2
Oberlin	1,857	1,794	3.5	1,544	16.2
Reeves	214	151	41.7	106	42.5
ASCENSION	37,086	27,927	32.8	22,387	24.7
Donaldsonville	7,367	6,082	21.1	4,150	46.6
Gonzales	4,512	3,252	38.7	1,642	98.1
Sorrento	1,182	1,151	2.7	0	.0
ASSUMPTION	19,654	17,991	9.2	17,278	4.1
Napoleonville	1,008	1,148	–12.2	1,260	–8.9
AVOYELLES	37,751	37,606	.4	38,031	–1.1
Bunkie	5,395	5,188	4.0	4,666	11.2
Cottonport	1,846	1,581	16.8	1,534	3.1
Evergreen	307	325	–5.5	382	–14.9
Hessmer	454	433	4.8	0	.0
Mansura	1,699	1,579	7.6	1,439	9.7
Marksville	4,519	4,257	6.2	3,635	17.1
Moreauville	807	815	–1.0	835	–2.4
Plaucheville	224	228	–1.8	277	–17.7
Simmesport	2,027	2,125	–4.6	1,510	40.7
BEAUREGARD	22,888	19,191	19.3	17,766	8.0
De Ridder	8,030	7,188	11.7	5,799	24.0
Merryville	1,286	1,232	4.4	1,383	–10.9
BIENVILLE	16,024	16,726	–4.2	19,105	–12.5
Arcadia	2,970	2,547	16.6	2,241	13.7
Bienville	287	305	–5.9	445	–31.5
Bryceland	65	89	–27.0	123	–27.6
Castor	178	142	25.4	171	–17.0
Gibsland	1,380	1,150	20.0	1,085	6.0
Jamestown	153	0	.0	0	.0
Mount Lebanon	102	0	.0	0	.0
Ringgold	1,731	953	81.6	1,007	–5.4
Saline	307	329	–6.7	357	–7.8

(Continued)

TABLE 6.—(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
BOSSIER	64,519	57,622	12.0	40,139	43.6
Benton	1,493	1,336	11.8	741	80.3
Bossier City	41,595	32,776	26.9	15,470	111.9
Haughton	885	611	44.8	501	22.0
Plain Dealing	2,116	1,357	55.9	1,321	2.7
CADDO	230,184	223,859	2.8	176,547	26.8
Gilliam	211	0	.0	0	.0
Greenwood	212	0	.0	0	.0
Hosston	428	0	.0	0	.0
Ida	370	0	.0	0	.0
Mooringsport	830	864	–3.9	709	21.9
Oil City	907	1,430	–36.6	422	238.9
Rodessa	273	0	.0	0	.0
Shreveport	182,064	164,372	10.8	127,206	29.2
Vivian	4,046	2,624	54.2	2,426	8.2
CALCASIEU	145,415	145,475	.0	89,635	62.3
De Quincy	3,448	3,928	–12.2	3,837	2.4
Iowa	1,857	1,857	.0	0	.0
Lake Charles	77,998	63,392	23.0	41,272	53.6
Sulphur	13,551	11,429	18.6	5,996	90.6
Vinton	3,454	2,987	15.6	2,597	15.0
Westlake	4,082	3,311	23.3	1,871	77.0
CALDWELL	9,354	9,004	3.9	10,293	–12.5
Clarks	889	940	–5.4	0	.0
Columbia	1,000	1,021	–2.1	920	11.0
Grayson	516	428	20.6	455	–5.9
CAMERON	8,194	6,909	18.6	6,244	10.7
CATAHOULA	11,769	11,421	3.0	11,834	–3.5
Harrisonburg	626	594	5.4	544	9.2
Jonesville	2,761	2,347	17.6	1,954	20.1
Sicily Island	630	761	–17.2	0	.0
CLAIBORNE	17,024	19,407	–12.3	25,063	–22.6
Athens	387	406	–4.7	487	–16.6
Haynesville	3,055	3,031	.8	3,040	–.3
Homer	4,483	4,665	–3.9	4,749	–1.8
Lisbon	151	229	–34.1	0	.0
CONCORDIA	22,578	20,467	10.3	14,398	42.2
Clayton	1,103	882	25.1	657	34.2
Ferriday	5,239	4,563	14.8	3,847	18.6
Ridgecrest	1,076	0	.0	0	.0
Vidalia	5,538	4,313	28.4	1,641	162.8

(Continued)

TABLE 6.–(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
DE SOTO	22,764	24,248	–6.1	24,398	–0.6
Grand Cane	284	322	–11.8	286	12.6
Keatchie	328	345	–4.9	0	.0
Logansport	1,330	1,371	–3.0	1,271	8.0
Longstreet	182	283	–35.7	224	26.3
Mansfield	6,432	5,839	10.2	4,440	31.5
South Mansfield	439	616	–28.7	276	123.2
Stanley	145	234	–38.0	0	.0
EAST BATON ROUGE	285,167	230,058	24.0	158,236	45.4
Baker	8,281	4,823	71.7	762	532.9
Baton Rouge	165,963	152,419	8.9	125,629	21.3
Zachary	4,964	3,268	51.9	1,542	111.9
EAST CARROLL	12,884	14,433	–10.7	16,302	–11.5
Lake Providence	6,183	5,781	7.0	4,123	40.2
EAST FELICIANA	17,657	20,198	–12.6	19,133	5.6
Clinton	1,884	1,568	20.2	1,383	13.4
Jackson	4,697	1,824	157.5	1,144	59.4
Norwood	348	427	–18.5	414	3.1
Slaughter	580	403	43.9	290	39.0
Wilson	606	0	.0	0	.0
EVANGELINE	31,932	31,639	.9	31,629	. .
Basile	1,779	1,932	–7.9	1,572	22.9
Mamou	3,275	2,928	11.9	2,254	29.9
Pine Prairie	515	387	33.1	0	.0
Turkey Creek	280	279	.4	0	.0
Ville Platte	9,692	7,512	29.0	6,633	13.3
FRANKLIN	23,946	26,088	–8.2	29,376	–11.2
Baskin	177	238	–25.6	117	103.4
Gilbert	746	472	58.1	452	4.4
Winnsboro	5,349	4,437	20.6	3,655	21.4
Wisner	1,339	1,254	6.8	738	69.9
GRANT	13,671	13,330	2.6	14,263	–6.5
Colfax	1,892	1,934	–2.2	1,651	17.1
Dry Prong	352	360	–2.2	377	–4.5
Georgetown	306	321	–4.7	355	–9.6
Montgomery	923	866	6.6	695	24.6
Pollock	341	366	–6.8	421	–13.1
IBERIA	57,397	51,657	11.1	40,059	29.0
Jeanerette	6,322	5,568	13.5	4,692	18.7
Loreauville	728	655	11.1	478	37.0
New Iberia	30,147	29,062	3.7	16,467	76.5
IBERVILLE	30,746	29,939	2.7	26,750	11.9
Grosse Tete	710	768	–7.6	548	40.1
Maringouin	1,365	1,168	16.9	898	30.1
Plaquemine	7,739	7,689	.7	5,747	33.8
Rosedale	621	674	–7.9	0	.0
White Castle	2,206	2,253	–2.1	1,839	22.5

(Continued)

TABLE 6.—(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
JACKSON	15,963	15,828	.9	15,434	2.6
Chatham	827	758	9.1	833	–9.0
Eros	164	176	–6.8	195	–9.7
Hodge	818	878	–6.8	1,386	–36.7
Jonesboro	5,072	3,848	31.8	3,097	24.2
North Hodge	640	680	–5.9	0	.0
Quitman	169	185	–8.6	204	–9.3
JEFFERSON	337,568	208,769	61.7	103,873	101.0
Grand Isle	2,236	2,074	7.8	0	.0
Gretna	24,875	21,967	13.2	13,813	59.0
Harahan	13,037	9,275	40.6	3,394	173.3
Kenner	29,858	17,037	75.3	5,535	207.8
Westwego	11,402	9,815	16.2	8,328	17.9
JEFFERSON DAVIS	29,554	29,825	–.9	26,298	13.4
Elton	1,598	1,595	.2	1,434	11.2
Fenton	404	429	–5.8	0	.0
Jennings	11,783	11,887	–.9	9,663	23.0
Lake Arthur	3,551	3,541	.3	2,849	24.3
Welsh	3,203	3,332	–3.9	2,416	37.9
LAFAYETTE	109,716	84,656	29.6	57,743	46.6
Broussard	1,707	1,600	6.7	1,237	29.3
Carencro	2,302	1,519	51.5	1,587	–4.3
Duson	1,199	1,033	16.1	707	46.1
Lafayette	68,908	40,400	70.6	33,541	20.4
Scott	1,334	902	47.9	688	31.1
Youngsville	1,002	946	5.9	769	23.0
LAFOURCHE	68,941	55,381	24.5	42,209	31.2
Golden Meadow	2,681	3,097	–13.4	0	.0
Lockport	1,995	2,221	–10.2	1,388	60.0
Thibodaux	14,925	13,403	11.4	7,730	73.4
LA SALLE	13,295	13,011	2.2	12,717	2.3
Jena	2,389	2,098	13.9	1,438	45.9
Olla	1,387	1,246	11.3	1,115	11.7
Tullos	600	594	1.0	732	–18.9
LINCOLN	33,800	28,535	18.5	25,782	10.7
Choudrant	555	465	19.4	395	17.7
Dubach	1,096	1,013	8.2	703	44.1
Grambling	4,407	3,144	40.2	0	.0
Ruston	17,365	13,991	24.1	10,372	34.9
Simsboro	412	363	13.5	0	.0
LIVINGSTON	36,511	26,974	35.4	20,054	34.5
Albany	700	557	25.7	0	.0
Corbin	189	0	.0	0	.0
Denham Springs	6,752	5,991	12.7	2,053	191.8
Livingston	1,398	1,183	18.2	0	.0
Port Vincent	387	340	13.8	0	.0
Springfield	268	0	.0	0	.0
Walker	1,363	912	49.5	500	82.4

(Continued)

TABLE 6.–(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
MADISON	15,065	16,444	–8.4	17,451	–5.8
Delta	153	111	37.8	150	–26.0
Mound	78	107	–27.1	105	1.9
Tallulah	9,643	9,413	2.4	7,758	21.3
MOREHOUSE	32,463	33,709	–3.7	32,038	5.2
Bastrop	14,713	15,193	–3.2	12,769	19.0
Bonita	533	574	–7.1	504	13.9
Collinston	397	497	–20.1	546	–9.0
Mer Rouge	819	853	–4.0	784	8.8
Oak Ridge	276	287	–3.8	287	.0
NATCHITOCHES	35,219	35,653	–1.2	38,144	–6.5
Ashland	211	0	.0	0	.0
Campti	1,078	1,045	3.2	1,014	3.1
Clarence	448	286	56.6	0	.0
Goldonna	337	292	15.4	364	–19.8
Natchitoches	15,974	13,924	14.7	9,914	40.4
Powhatan	277	0	.0	0	.0
Provencal	530	570	–7.0	0	.0
Robeline	274	308	–11.0	350	–12.0
ORLEANS	593,471	627,525	–5.4	570,445	10.0
New Orleans	593,471	627,525	–5.4	570,445	10.0
OUACHITA	115,387	101,663	13.5	74,713	26.1
Monroe	59,374	52,219	13.7	38,572	35.4
Sterlington	1,118	0	.0	0	.0
West Monroe	14,868	15,215	–2.3	10,302	47.7
PLAQUEMINES	25,225	22,545	11.9	14,239	58.3
POINTE COUPEE	22,002	22,488	–2.2	21,841	3.0
Fordoche	488	0	.0	0	.0
Livonia	611	430	42.1	0	.0
Morganza	836	937	–10.8	817	14.7
New Roads	3,945	3,965	–.5	2,818	40.7
RAPIDES	118,078	111,351	6.0	90,648	22.8
Alexandria	41,557	40,279	3.2	34,913	15.4
Boyce	1,240	1,094	13.3	981	11.5
Cheneyville	1,082	1,037	4.3	918	13.0
Forest Hill	370	302	22.5	365	–17.3
Glenmora	1,651	1,447	14.1	1,556	–7.0
Lecompte	1,518	1,485	2.2	1,443	2.9
Mc Nary	220	0	.0	0	.0
Pineville	8,951	8,636	3.6	6,423	34.5
Woodworth	409	320	27.8	392	–18.4
RED RIVER	9,226	9,978	–7.5	12,113	–17.6
Coushatta	1,492	1,663	–10.3	1,788	–7.0
Edgefield	201	0	.0	0	.0
Hall Summit	190	0	.0	0	.0

(Continued)

TABLE 6.–(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
RICHLAND	21,774	23,824	–8.6	26,672	–10.7
Delhi	2,887	2,514	14.8	1,861	35.1
Mangham	544	521	4.4	554	–6.0
Rayville	3,962	4,052	–2.2	3,138	29.1
SABINE	18,638	18,564	.4	20,880	–11.1
Converse	375	291	28.9	311	–6.4
Florien	639	496	28.8	0	.0
Many	3,112	3,164	–1.6	1,681	88.2
Noble	209	206	1.5	238	–13.4
Pleasant Hill	826	907	–8.9	856	6.0
Zwolle	2,169	32,186	59.0	1,555	–14.7
ST. BERNARD	51,185	32,186	59.0	11,087	190.3
ST. CHARLES	29,550	21,219	39.3	13,363	58.8
ST. HELENA	9,937	9,162	8.5	9,013	1.7
Greensburg	652	512	27.3	423	21.0
Montpelier	211	197	7.1	0	.0
ST. JAMES	19,733	18,369	7.4	15,334	19.8
Gramercy	2,567	2,094	22.6	1,184	76.9
Lutcher	3,274	3,274	.0	2,198	49.0
ST. JOHN THE BAPTIST	23,813	18,439	29.1	14,861	24.1
ST. LANDRY	80,364	81,493	–1.4	78,476	3.8
Arnaudville	1,673	1,184	41.3	872	35.8
Cankton	260	0	.0	0	.0
Eunice	11,390	11,326	.6	8,184	38.4
Grand Coteau	1,301	1,165	11.7	1,103	5.6
Krotz Springs	1,435	1,057	35.8	866	22.1
Leonville	512	526	–2.7	514	2.3
Melville	2,076	1,939	7.1	1,901	2.0
Opelousas	20,121	17,417	15.5	11,659	49.4
Palmetto	312	430	–27.4	457	–5.9
Port Barre	2,133	1,876	13.7	1,066	76.0
Sunset	1,675	1,307	28.2	1,080	21.0
Washington	1,473	1,291	14.1	1,291	.0
ST. MARTIN	32,453	29,063	11.7	25,353	10.3
Breaux Bridge	4,942	3,303	49.6	2,492	32.5
Parks	491	413	18.9	460	–10.2
St. Martinville	7,153	6,468	10.6	4,614	40.2
ST. MARY	60,752	48,833	24.4	35,848	36.2
Baldwin	2,117	1,548	36.8	1,138	36.0
Berwick	4,168	3,880	7.4	2,619	48.1
Franklin	9,325	8,673	7.5	6,144	41.2
Morgan City	16,586	13,540	22.5	9,759	38.7
Patterson	4,409	2,923	50.8	1,938	50.8

(Continued)

TABLE 6.—(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
ST. TAMMANY	63,585	38,643	64.5	26,988	43.2
Abita Springs	839	655	28.1	559	17.2
Covington	7,170	6,754	6.2	5,113	32.1
Folsom	249	225	10.7	166	35.5
Madisonville	801	860	–6.9	861	–.1
Mandeville	2,282	1,740	31.1	1,368	27.2
Pearl River	1,361	964	41.2	637	51.3
Slidell	16,101	6,356	153.3	3,464	83.5
Sun	288	224	28.6	0	.0
TANGIPAHOA	65,875	59,434	10.8	53,218	11.7
Amite City	3,593	3,316	8.4	2,804	18.3
Hammond	12,487	10,563	18.2	8,010	31.9
Independence	1,770	1,941	–8.8	1,606	20.9
Kentwood	2,736	2,607	4.9	2,417	7.9
Ponchatoula	4,545	4,727	–3.9	4,090	15.6
Roseland	1,273	1,254	1.5	1,038	20.8
Tangipahoa	469	465	.9	352	32.1
Tickfaw	370	317	16.7	0	.0
TENSAS	9,732	11,796	–17.5	13,209	–10.7
Newellton	1,403	1,453	–3.4	1,280	13.5
St. Joseph	1,864	1,653	12.8	1,218	35.7
Waterproof	1,438	1,412	1.8	1,180	19.7
TERREBONNE	76,049	60,771	25.1	43,328	40.3
Houma	30,922	22,561	37.1	11,505	96.1
UNION	18,447	17,624	4.7	19,141	–7.9
Bernice	1,794	1,641	9.3	1,524	7.7
Farmerville	3,416	2,727	25.3	2,173	25.5
Junction City	733	639	14.7	514	24.3
Lillie	160	0	.0	0	.0
Marion	796	685	16.2	685	.0
Spearsville	197	0	.0	0	.0
VERMILION	43,071	38,855	10.9	36,929	5.2
Abbeville	10,996	10,414	5.6	9,338	11.5
Delcambre	1,975	1,857	6.4	1,463	26.9
Erath	2,024	2,019	.2	1,514	33.4
Gueydan	1,984	2,156	–8.0	2,041	5.6
Kaplan	5,540	5,267	5.2	4,562	15.5
Maurice	476	411	15.8	335	22.7
VERNON	53,794	18,301	193.9	18,974	–3.5
Hornbeck	525	374	40.4	524	–28.6
Leesville	8,928	4,689	90.4	4,670	.4
Rosepine	587	414	41.8	334	24.0
Simpson	491	0	.0	0	.0
WASHINGTON	41,987	44,015	–4.6	38,371	14.7
Angie	317	254	24.8	230	10.4
Bogalusa	18,412	21,423	–14.1	17,798	20.4
Franklinton	3,562	3,141	13.4	2,342	34.1
Varnado	320	331	–3.3	306	8.2

(Continued)

TABLE 6.—(Continued)

Parish and Place	Population 1970	Population 1960	Change 1960-70	Population 1950	Change 1950-60
WEBSTER	39,939	39,701	.6	35,704	11.2
Cotton Valley	1,261	1,145	10.1	1,188	-3.6
Cullen	1,956	2,194	-10.8	0	.0
Dixie Inn	456	399	14.3	0	.0
Doyline	716	1,061	-32.5	1,170	-9.3
Dubberly	212	249	-14.9	0	.0
Heflin	314	289	8.7	0	.0
Minden	13,996	12,785	9.5	9,787	30.6
Sarepta	882	737	19.7	0	.0
Shongaloo	173	0	.0	0	.0
Sibley	869	595	46.1	623	-4.5
Springhill	6,496	6,437	.9	3,383	90.3
WEST BATON ROUGE	16,864	14,796	14.0	11,738	26.1
Addis	724	590	22.7	505	16.8
Brusly Landing	1,282	544	135.7	493	10.3
Port Allen	5,728	5,026	14.0	3,097	62.3
WEST CARROLL	13,028	14,177	-8.1	17,248	-17.8
Epps	448	411	9.0	308	33.4
Forest	221	0	.0	0	.0
Kilbourne	370	227	63.0	0	.0
Oak Grove	1.980	1,797	10.2	1,796	.1
Pioneer	188	154	22.1	0	.0
WEST FELICIANA	11,376	12,395	-8.2	10,169	21.9
St. Francisville	1,603	1,661	-3.5	936	77.5
WINN	16,369	16,034	2.1	16,119	-0.5
Calvin	286	232	23.3	0	.0
Dodson	457	512	-10.7	375	36.5
Sikes	237	233	1.7	342	-31.9
Winnfield	7,142	7,022	1.7	5,629	24.7

TABLE 7.—Population and Percent Change of Unincorporated Places of 1,000 or More in 1960 and 1970

Unincorporated places of 1,000 or more	Parish	1970	1960	Percent change
Alexandria Southwest	Rapides	3,151	2,782	13.3
Allemands	Lafourche St. Charles	2,318	1,167	98.6
Amelia	St. Mary	2,292	....*	....
Anandale	Rapides	1,779	2,827	–37.1
Bayou Cane	Terrebonne	9,077	3,173	186.1
Bayou Vista	St. Mary	5,121	....*	....
Buras - Triumph	Plaquemines	4,113	4,908	–16.2
Cooper Road	Caddo	9,034	....*	....
England	Rapides	3,715	....*	....
Garyville	St. John the Baptist	2,474	2,389	3.6
Hahnville	St. Charles	2,483	1,297	91.4
Hammond East	Tangipahoa	1,342	1,462	–8.2
Harvey	Jefferson	6,347	....*	....
Hollywood	Calcasieu	2,328	1,750	33.0
Jefferson Heights	Jefferson	16,489	19,353	–14.8
Lafitte	Jefferson	1,223	....*	....
Laplace	St. John the Baptist	5,953	3,541	68.1
Larose	Lafourche	4,267	2,796	52.6
Little Farms	Jefferson	15,713	....*	....
Luling	St. Charles	3,255	2,122	53.4
Marrero	Jefferson	29,015	....*	....
Metairie	Jefferson	135,816	....*	....
Mimosa Park	St. Charles	1,624	....*	....
New Sarpy	St. Charles	1,643	1,259	30.5
Norco	St. Charles	4,773	4,682	1.9
North Fort Polk	Vernon	7,955	....*	....
Plaquemine Southwest	Iberville	1,224	1,272	–3.8
Port Sulphur	Plaquemines	3,022	2,868	5.4
Raceland	Lafourche	4,880	3,666	33.1
Reserve	St. John the Baptist	6,381	5,297	20.5
Saint Rose	St. Charles	2,106	1,099	91.6
Samtown	Rapides	4,210	4,008	5.0
Scotlandville	East Baton Rouge	22,557	....*	....
Seymourville	Iberville	2,506	1,788	40.2
South Fort Polk	Vernon	15,600	....*	....
Sulphur South	Calcasieu	1,108	1,351	–18.0
Terry	Jefferson	13,832	....*	....
Vacherie	St. James	2,145	....*	....
Wardville	Rapides	1,087	1,086	0.1

*Not listed as separate entity in 1960.

Composition of the Population

Louisiana's population is now more urban than it has ever been before. Two-thirds (66.1 percent) of the people of the state live in places defined as urban by the U.S. Census. The urban population includes all persons living in places of 2,500 or more inhabitants. Metropolitan areas are defined as a parish which contains a city of 50,000 inhabitants or more. Adjoining parishes are included in a metropolitan area if they are socially and economically interdependent with the central city. Over half of Louisiana's inhabitants reside in such areas.

Louisiana and the other states located in the Southern part of the United States remains more rural than the rest of the nation, although all southern states are rapidly becoming more urban, with the exception of West Virginia. According to the 1970 Census, 74 percent of the people of the United States live in urban places compared with 70 percent in 1960. In this regard, it is interesting to note that 42 of the 50 states have an urban population which includes 50 percent or more of the people residing in the state. Only eight states now have more rural inhabitants than urban inhabitants. This number contrasts with 11 states in 1960. Mississippi, with a 56 percent rural population, is the only neighbor state to Louisiana which remains a predominantly rural state. Arkansas, which was predominantly rural in the past, now has 50 percent of its population located in urban places. Texas is 80 percent urban.

In Louisiana, as can be seen in Table 8 and Figure 5, Orleans and surrounding parishes are the most urban of all parishes. Orleans parish is 100 percent urban, while Jefferson is 96 percent urban and St. Bernard is 91 percent urban. Other highly urban parishes are East Baton Rouge, 87 percent urban; Caddo, 86 percent urban; Ouachita, 79 percent urban, and Calcasieu, 75 percent urban. By contrast, 10 parishes are completely rural. All-rural parishes include Assumption, Caldwell, Cameron, Grant, LaSalle, Red River, St. Helena, Tensas, West Carroll and West Feliciana. Despite the urban predominance in population, more than half the parishes in Louisiana are still over 50 percent rural, 43 parishes in all (see Figure 5).

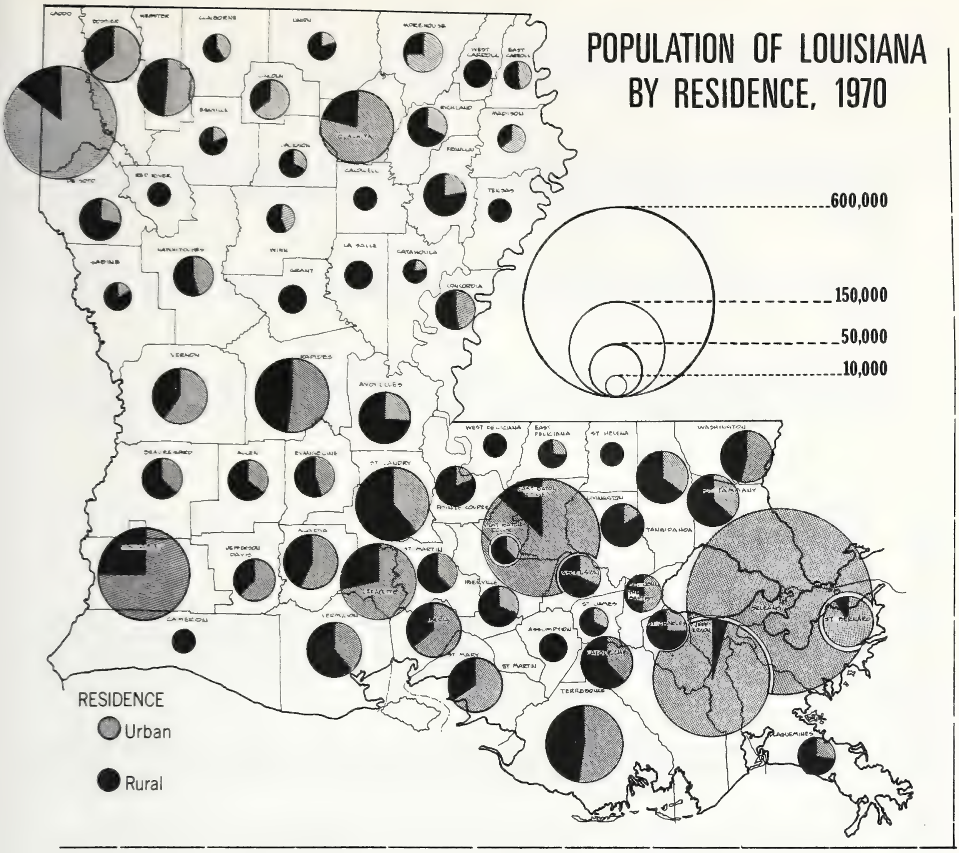

POPULATION OF LOUISIANA
BY RESIDENCE, 1970
600,000
150,000
50,000
10,000
RESIDENCE
Urban
Rural
CADDO
BOSSIER
WEBSTER
CLAIBORNE
UNION
MOREHOUSE
WEST CARROLL
EAST CARROLL
LINCOLN
BIENVILLE
RICHLAND
MADISON
JACKSON
CALDWELL
FRANKLIN
RED RIVER
DE SOTO
TENSAS
WINN
LA SALLE
CATAHOULA
NATCHITOCHES
SABINE
GRANT
CONCORDIA
VERNON
RAPIDES
AVOYELLES
WEST FELICIANA
EAST FELICIANA
ST HELENA
WASHINGTON
BEAUREGARD
ALLEN
EVANGELINE
ST LANDRY
POINTE COUPEE
EAST BATON ROUGE
LIVINGSTON
TAMMANY
TANGIPAHOA
JEFFERSON DAVIS
ACADIA
ST MARTIN
LAFAYETTE
IBERVILLE
ASCENSION
CAMERON
VERMILION
IBERIA
ST JAMES
ASSUMPTION
ST CHARLES
JEFFERSON
ORLEANS
ST BERNARD
ST MARY
ST MARTIN
LAFOURCHE
TERREBONNE
PLAQUEMINES

FIGURE 5

TABLE 8.—Louisiana Population Count, by Urban-Rural Components, 1970 and 1960

Parish	Total population		Urban population				Rural population			
	1970	1960	1970	Percent	1960	Percent	1970	Percent	1960	Percent
Acadia	52,109	49,931	29,591	56.8	27,857	55.8	22,518	43.2	22,074	44.2
Allen	20,794	19,867	7,301	35.1	6,618	33.3	13,493	64.9	13,249	66.7
Ascension	37,086	27,927	11,879	32.0	9,334	33.4	25,207	68.0	18,593	66.6
Assumption	19,654	17,991	0	0	0	0	19,654	100.0	17,991	100.0
Avoyelles	37,751	37,606	9,914	26.3	9,445	25.1	27,837	73.3	28,161	74.9
Beauregard	22,888	19,191	8,030	35.1	7,188	37.5	14,858	64.9	12,003	62.5
Bienville	16,024	16,726	2,970	18.5	2,547	15.2	13,054	81.5	14,179	84.8
Bossier	64,519	57,622	41,845	64.9	38,005	66.0	22,674	35.1	19,617	34.0
Caddo	230,184	223,859	196,765	85.5	180,903	80.8	33,419	14.5	42,956	19.2
Calcasieu	145,415	145,475	108,713	74.8	107,459	73.9	36,702	25.2	38,016	26.1
Caldwell	9,354	9,004	0	0	0	0	9,354	100.0	9,004	100.0
Cameron	8,194	6,909	0	0	0	0	8,194	100.0	6,909	100.0
Catahoula	11,769	11,421	2,761	23.5	0	0	9,008	76.5	11,421	100.0
Claiborne	17,024	19,407	7,538	44.3	7,696	39.7	9,486	55.7	11,711	60.3
Concordia	22,578	20,467	10,777	47.7	8,876	43.4	11,801	52.3	11,591	56.6
DeSoto	22,764	24,248	6,432	28.3	5,839	24.1	16,332	71.7	18,409	75.9
East Baton Rouge	285,167	230,058	247,869	86.9	195,780	85.1	37,298	13.1	34,278	14.9
East Carroll	12,884	14,433	6,183	48.0	5,781	40.1	6,701	52.0	8,652	59.9
East Feliciana	17,657	20,198	4,697	26.6	0	0	12,960	73.4	20,198	100.0
Evangeline	31,932	31,639	12,967	40.6	10,440	33.0	18,965	59.4	21,199	67.0
Franklin	23,946	26,088	5,349	22.3	4,437	33.0	18,597	77.7	21,651	67.0
Grant	13,671	13,330	0	0	0	0	13,671	100.0	13,330	100.0
Iberia	57,397	51,657	36,469	63.5	34,630	67.0	20,928	36.5	17,027	33.0
Iberville	30,746	29,939	10,245	33.3	7,689	25.7	20,501	66.7	22,250	74.3
Jackson	15,963	15,828	5,072	31.8	3,848	24.3	10,891	68.2	11,980	75.7
Jefferson	337,568	208,769	323,507	95.8	196,458	94.1	14,061	4.2	12,311	5.9
Jefferson Davis	29,554	29,825	18,537	62.7	18,760	62.9	11,017	37.3	11,065	37.1
Lafayette	109,716	84,656	78,544	71.6	47,082	55.6	31,172	28.4	37,574	44.4
Lafourche	68,941	55,381	26,753	38.8	22,962	41.5	42,188	61.2	32,419	58.5
LaSalle	13,295	13,011	0	0	0	0	13,295	100.0	13,011	100.0
Lincoln	33,800	28,535	21,772	64.4	17,135	60.0	12,028	35.6	11,400	40.0
Livingston	36,511	26,974	6,752	18.5	5,991	22.2	29,759	81.5	20,983	77.8

(Continued)

TABLE 8.–(Continued)

Parish	Total population		Urban population				Rural population			
	1970	1960	1970	Percent	1960	Percent	1970	Percent	1960	Percent
Madison	15,065	16,444	9,643	64.0	9,413	57.2	5,422	36.0	7,031	42.8
Morehouse	32,463	33,709	14,713	45.3	15,193	45.1	17,750	54.7	18,516	54.9
Natchitoches	35,219	35,653	15,974	45.4	13,924	39.1	19,245	54.6	21,729	60.9
Orleans	593,471	627,525	591,502	99.7	627,525	100.0	1,969	0.3	0	0
Ouachita	115,387	101,663	90,567	78.5	80,546	79.2	24,820	21.5	21,117	20.8
Plaquemines	25,225	22,545	7,135	28.3	7,776	34.5	18,090	71.7	14,769	65.5
Pointe Coupee	22,002	22,488	3,945	17.9	3,965	17.6	18,057	82.1	18,523	82.4
Rapides	118,078	111,351	61,584	52.2	58,532	52.6	56,494	47.8	52,819	47.4
Red River	9,226	9,978	0	0	0	0	9,226	100.0	9,978	100.0
Richland	21,774	23,824	6,849	31.5	6,566	27.6	14,925	68.5	17,258	72.4
Sabine	18,638	18,564	3,112	16.7	3,164	17.0	15,526	83.3	15,400	83.0
St. Bernard	51,185	32,186	46,719	91.3	21,254	66.0	4,466	8.7	10,932	34.0
St. Charles	29,550	21,219	8,028	27.2	4,682	22.1	21,522	72.8	16,537	77.9
St. Helena	9,937	9,162	0	0	0	0	9,937	100.0	9,162	100.0
St. James	19,733	18,369	6,478	32.8	3,274	17.8	13,255	67.2	15,095	82.2
St. John the Baptist	23,813	18,439	12,334	51.8	8,838	47.9	11,479	48.2	9,601	52.1
St. Landry	80,364	81,493	31,399	39.1	28,743	35.3	48,965	60.9	52,750	64.7
St. Martin	32,453	29,063	12,095	37.3	9,771	33.6	20,358	62.7	19,292	66.4
St. Mary	60,752	48,833	39,609	65.2	29,016	59.4	21,143	34.8	19,817	40.6
St. Tammany	63,585	38,643	23,271	36.6	13,110	33.9	40,314	63.4	25,533	66.1
Tangipahoa	65,875	59,434	23,361	35.5	21,213	35.7	42,514	64.5	38,221	64.3
Tensas	9,732	11,796	0	0	0	0	9,732	100.0	11,796	100.0
Terrebonne	76,049	60,771	39,999	52.6	31,640	52.1	36,050	47.4	29,131	47.9
Union	18,447	17,624	3,416	18.5	2,727	15.5	15,031	81.5	14,897	84.5
Vermilion	43,071	38,855	16,536	38.4	15,681	40.4	26,535	61.6	23,174	59.6
Vernon	53,794	18,301	32,483	60.4	4,689	25.6	21,311	39.6	13,612	74.4
Washington	41,987	44,015	21,974	52.3	24,564	55.8	20,013	47.7	19,451	44.2
Webster	39,939	39,701	20,492	51.3	19,222	48.4	19,447	48.7	20,479	51.6
West Baton Rouge	16,864	14,796	6,558	38.9	5,796	39.2	10,306	61.1	9,000	60.8
West Carroll	13,028	14,177	0	0	0	0	13,028	100.0	14,177	100.0
West Feliciana	11,376	12,395	0	0	0	0	11,376	100.0	12,395	100.0
Winn	16,369	16,034	7,142	43.6	7,022	43.8	9,227	56.4	9,012	56.2

Summary and Implications

The changes in the population of Louisiana from 1960 to 1970 are summarized briefly here, and some of their implications for the future of the state are elaborated.

1. The total population of the state increased at a slower rate than it had from 1950 to 1960. Taken by itself this fact suggests that planning for the provision of services to the population will not be unduly strained. On the other hand, there are considerable regional variations in the rate of growth. Some areas, principally in North Central Louisiana, continue to face the social dilemma of a declining population, which is reflected in problems such as aging of the local population, under-employment, low income, local taxation erosion and poorly supported social institutions like churches and business places. By contrast, some areas (principally those including or near metropolitan centers) face the challenge of a growing population and its associated increasing needs for educational, medical and other services.

2. The growth of the state's population continues to be largely an urban phenomenon, while rural areas typically continue to decline. Further technological changes in agriculture are likely to make this trend persist. This ongoing shift in the rural-urban composition of the state's population can be expected to have far-reaching consequences. From the point of view of the future composition of the population, the impact of urbanization will likely be seen in a reduction of the state's birth rate. At the same time, the values, attitudes and goals of the people can be expected to change over time. The latter will have political and other repercussions.

3. Although the population of the state has become more concentrated in metropolitan areas, these areas have become more suburban in character. In this respect, population distribution in Louisiana is following trends apparent elsewhere in the United States. These trends portend problems of tax bases, schooling, transportation, police protection and others in central cities. They suggest consideration should be given to programs designed to relocate people in rural areas, among other things.

4. While Louisiana still has one of the largest nonwhite populations of any state, the proportion of nonwhites in its population has declined since 1960. Substantial net outmigration of nonwhites and some inmigration of whites continue and account for this trend.

All in all, although Louisiana is becoming increasingly urbanized, much of the state still reflects a rural and agricultural character in the composition and distribution of the population. This fact has relevance for many types of programs, in that it indicates certain types of attitudes and values continue to prevail. Should the urbanization of the state continue, one can be sure these values will change and create many new problems and challenges for the people of Louisiana.

Effects of Some Liming Materials And Calcium Sulfate on Soil Reaction And Exchangeable Calcium And Magnesium

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DOYLE CHAMBERS, DIRECTOR

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Effects of Some Liming Materials and Calcium Sulfate on Soil Reaction and Exchangeable Calcium and Magnesium

W. J. PEEVY, R. H. BRUPBACHER AND J. E. SEDBERRY, JR.[1]

Introduction

Several kinds of liming materials are used in Louisiana to correct soil acidity and add calcium and magnesium to the soil. Other materials which may be used for these purposes are also available. In addition, there are materials which will add calcium or magnesium but which may increase soil acidity.

The purpose of this study was to determine the effects of some of these materials on the pH and on the exchangeable calcium and magnesium contents of a soil.

The effects of these materials on the pH of other soils may be very different from the effects on the soil used in this study, because the kinds and amounts of clay and humus in a soil influence greatly the effect of any material on the pH of that soil. However, the trends of the effects would be similar, although the magnitude may be different.

The effects of these materials on the increase of exchangeable calcium and magnesium in other soils would be the same as in the soil used in this study, because these effects are influenced by the composition and fineness of the lime and not by the soil to which it is applied.

Experimental Materials and Methods

The soil used in this study was a Gallion fine sandy loam collected in Caldwell Parish. It had a pH of 5.0 and a cation exchange capacity of 6.74 meg/100g and was 54 percent base saturated. The "lime requirement," as determined by the method employed in the LSU Soil Testing Laboratory,[2] was 2 tons per acre to raise the pH to 6.3. The soil contained 307 ppm of exchangeable calcium and 90 ppm of exchangeable magnesium, as determined with the use of ammonium acetate.

The chemical (excluding impurities) and physical compositions of the materials used in the study are given in Table 1.

---

[1] Professor, Associate Professor and Professor, respectively, Department of Agronomy.

[2] Louisiana Agricultural Experiment Station Bulletin No. 632.

TABLE 1.—Composition of liming materials added to soil

Liming materials	Chemical composition (excluding impurities)	Chemical expression	Percent passing 8-mesh sieve	Percent passing 100-mesh sieve	Calcium carbonate equivalent	Percent calcium	Percent calcium carbonate	Percent magnesium	Percent magnesium carbonate
Aragonite	Calcium carbonate	$CaCO_3$	100	7.7	92.5	37	92.5	0	0
Hydrated lime	Calcium hydroxide	$Ca(OH)_2$	100	100	127.6	51	0	0	0
Oystershell flour	Calcium carbonate	$CaCO_3$	100	43	92.7	37.1	92.7	0	0
Calcic agricultural limestone	Calcium carbonate	$CaCO_3$	98.8	34.6	94.6	37.5	93.7	0.2	0.8
Dolomitic sample T-462	Calcium carbonate and magnesium carbonate	$CaCO_3$ and $MgCO_3$	99.4	39.2	97.2	30.3	75.7	5.16	18.1
Dolomitic sample T-463	Calcium carbonate and magnesium carbonate	$CaCO_3$ and $MgCO_3$	100	97.6	97.7	29.7	74.4	5.6	19.6
Dolomitic sample A. L.	Calcium carbonate and magnesium carbonate	$CaCO_3$ and $MgCO_3$	100	43.7	91.9	20	50	10	35.2
Gypsum	Calcium sulfate	$CaSO_4 \cdot 2H_2O$	100	100	—	23.2	—	0.2	—

The aragonite used in this study was obtained from ocean deposits. It also occurs in mines and caves. It is chemically the same as calcite ($CaCO_3$).

The hydrated lime is similar to that which can be purchased in most outlets that sell garden and yard products. It is calcium hydroxide.

The oystershell flour is derived from the crushing of such shells. Other ground sea shells are also used for liming purposes. They contain calcium carbonate.

The calcic agricultural limestone is a product being sold in Louisiana. It contains calcium carbonate.

The T-462 and T-463 dolomitic samples are products sold or available for sale in Louisiana. They contain fairly large amounts of calcium carbonate and medium amounts of magnesium carbonate. The two samples were used in this study to see if there was any real advantage in applying a very finely ground product (T-463) as compared with the products usually applied for liming purposes (T-462).

The A. L. dolomitic sample is a high grade dolomitic limestone being sold in Louisiana. It contains about 50 percent calcium carbonate and about 35 percent magnesium carbonate.

The gypsum is a sample of a material being sold in Louisiana by a national gypsum company. Although it does supply calcium to the soil, it is not a liming material because it increases rather than decreases soil acidity. It is calcium sulfate.

Each of the materials, except the hydrated lime, $Ca(OH)_2$, was added to the soil at a rate equivalent to 4,000 pounds per acre. The hydrated lime was added at the rate of 2,240 pounds per acre, because (1) it was a powder and therefore more available than the coarser ground agricultural limestone, and (2) a pound of hydrated lime, $Ca(OH)_2$, has a greater effect on neutralizing acids than does a pound of ground limestone ($CaCO_3$). Each treatment was replicated four times. The materials were mixed thoroughly with the soil and placed in 1-pint jars. Water was then added, and the soil was maintained at approximately field capacity and incubated at approximately 75 F for 8 months. The soil in each jar was then air-dried, mixed thoroughly, and analyzed for pH, exchangeable calcium and exchangeable magnesium.

Results and Discussion

Effects on Soil pH

There were considerable differences in the effects of the various liming materials on soil pH after 8 months, as shown in Table 2. The least effect was obtained with hydrated lime. This was probably due in part to the fact that this material reacted quickly with the soil, and then there was sufficient time for the soil to absorb carbon dioxide

TABLE 2.—Effects of liming materials on pH of Gallion fine sandy loam after eight months

Liming materials added	Rate added, tons per acre	Soil pH
Check	0	4.9
Aragonite	2	6.1
Hydrated lime	1.12	5.8
Oystershell flour	2	6.3
Calcic agricultural limestone	2	6.1
Dolomitic sample T-462	2	6.1
Dolomitic sample T-463	2	6.3
Dolomitic sample A.L.	2	5.8
Gypsum	2	4.6

from the air and for carbonic acid to be formed, thus lowering the pH of the soil.

The A. L. dolomitic lime also had considerably less effect on pH than the other materials. This was probably caused by the fact that the purity was only 91 percent, and by the fact that dolomitic limestone is harder and reacts more slowly than calcic limestone.

The oystershell "flour" and sample T. 463 had the greatest effects on soil pH. The oystershell "flour" did not have as great an effect as anticipated, partly because it had a purity of only 93 percent, and because only 43 percent passed a 100-mesh sieve. It was not as finely ground as the word "flour" implies. The sample T. 463 had a purity ($CaCO_3$ equivalent) of about 98 percent, and about 98 percent passed a 100-mesh sieve. Therefore, it would be expected to have a greater effect than coarser materials, such as sample T. 462 or the calcic agricultural limestone.

The aragonite used in this study proved to be a quite highly effective material, even though only about 8 percent passed a 100-mesh sieve. Since it compared well with other materials in its effect on pH and exchangeable calcium, it would be a good lime because of its uniformity in particle size (about like white clover seed). It contained very little dust. It should distribute well and evenly.

The calcium sulfate (gypsum) had a depressing effect on soil pH. This material is not a liming material in the usual sense, but it does supply calcium. It should be used as a source of calcium (1) where the soil pH is high yet the calcium is low, (2) where a slight decrease in pH is either desired or not harmful and (3) where the addition of sulfate is not harmful.

Effects on Exchangeable Calcium

The effects of the liming materials on exchangeable calcium, presented in Table 3, varied from an increase of 84 to 273 ppm per ton of material applied. This variation was caused by differences in chemical composition, purity and fineness of grind. The A. L. dolomitic limestone had the least effect because it contained a large amount of magnesium carbonate (35 percent) and only about 50 percent calcium carbonate. This would be a good type of material to use where magnesium is low, but not where this element is in good supply.

The dolomitic samples T. 462 and T. 463 supplied more exchangeable calcium than did the higher grade A. L. dolomitic limestone, but they contained about 80 percent calcium carbonate and only about 18 to 20 percent magnesium carbonate. The T. 462 and T. 463 materials would be desirable where large amounts of calcium and small amounts of magnesium are needed. Sample T. 463 resulted in a little more exchangeable calcium and a little higher pH in the 8 months of the experiment because this material was more finely ground. However, this finely ground material would not ship as well as Sample T. 462. The wind could also blow it badly during application.

The highest amounts of exchangeable calcium were obtained with the calcium hydroxide, oystershell flour, calcic agricultural lime and aragonite. Such materials as these would be desirable where no magnesium is needed. Since calcium hydroxide is very powdery, difficult to apply and also more expensive, its use is generally limited to gardens or other small areas. The calcium sulfate would be a fair source of calcium—but only where the pH could also be lowered slightly without harmful effects, or where the sulfate would not be harmful.

When any of these or similar materials are added to the soil, the farmer could estimate from the data in Table 3 approximately how much increase in exchangeable calcium to expect.

TABLE 3.—Effects of liming materials on exchangeable calcium in Gallion fine sandy loam after eight months

Liming materials added to soil	Rate added, tons per acre	Exchangeable calcium	Increase in exchangeable calcium	Increase in exchangeable calcium per ton of material
		parts per million		
Check	0	307	—	—
Aragonite	2	625	318	159
Hydrated lime	1.12	613	306	273
Oystershell flour	2	666	359	180
Calcic agricultural limestone	2	627	320	160
Dolomitic sample T-462	2	550	243	122
Dolomitic sample T-463	2	592	285	143
Dolomitic sample A. L.	2	474	167	84
Gypsum	2	483	176	88

Effects on Exchangeable Magnesium

Only three of the materials had any appreciable effect on exchangeable magnesium, as shown in Table 4. The calcium sulfate contained a little magnesium and increased the exchangeable magnesium slightly. The increases in exchangeable magnesium per ton of material applied were 32, 36 and 57 ppm from samples T. 462 and T. 463 and from the A. L. dolomitic source, respectively.

When soil tests for exchangeable magnesium are made and these kinds of materials are added, the farmer could estimate from the data in Table 4 approximately how much increase he may expect in exchangeable magnesium.

TABLE 4.—Effects of liming materials on exchangeable magnesium in Gallion fine sandy loam after eight months

Liming materials added to soil	Rate added, tons per acre	Exchangeable magnesium in soil	Increase in exchangeable magnesium	Increase in exchangeable magnesium per ton of material added
		parts per million		
Check	0	90	—	—
Aragonite	2	87	—	—
Hydrated lime	1.12	90	—	—
Oystershell flour	2	89	—	—
Calcic agricultural limestone	2	92	2	1
Dolomitic sample T-462	2	153	63	32
Dolomitic sample T-463	2	161	71	36
Dolomitic sample A. L.	2	204	114	57
Gypsum	2	96	6	3

Lasting Effects of Materials Added

The calcium hydroxide reacted quite rapidly and completely in the soil and gave the largest increase in exchangeable calcium per ton of material applied. However, since only 2,240 pounds were added, as compared with 4,000 pounds of the other materials, about 400 pounds less total calcium was applied than was contained in other calcic materials. These different amounts were added because the calcium hydroxide reacts more quickly and is, therefore, much more readily available than ordinary ground limestone. It also has a greater neutralizing ability. However, the slowly available portion of ground limestone will act as a reserve and maintain the calcium and magnesium supplies and pH much longer than will the faster-reacting calcium hydroxide. Only about one-half of most ordinary ground limestone will be effective in raising the pH or increasing calcium or magnesium contents of the soil. The other half of the limestone will react more slowly and maintain these levels for a few years, but for how long will depend on fineness of grind. Also, the greater the initial application of limestone, the larger the "reserve" portion will be, and the longer it will maintain the soil pH and calcium and magnesium levels of the soil. Liming recommendations based upon soil tests should be followed so that the hazards of over-liming may be avoided.

Summary

The effects of several liming materials and calcium sulfate on soil pH and on the exchangeable calcium and exchangeable magnesium contents of a soil were studied.

The effects of the liming materials on the pH of the soil used in this study varied considerably, depending on the kind of material used, its purity and fineness of grind. The effects of these materials on the pH of other soils may be greater or smaller than on this soil, because the effect on soil pH is dependent to a large extent on the clay and humus contents of the soil.

The calcium sulfate caused the pH of this soil to be lowered. This would also occur in other soils, but again the effect will be greatly influenced by the clay and humus contents of the soils to which it is applied.

The effects of these materials on the exchangeable calcium in this soil ranged from an increase of 84 to 273 ppm per ton of material applied. This variation was caused by differences in chemical composition, purity and fineness of the materials applied.

The effects of these materials on the exchangeable magnesium in this soil ranged from an increase of 32 to 57 ppm per ton of material applied, again depending on the chemical composition, purity and fineness of the material applied.

The amounts of exchangeable calcium and magnesium added to other soils would be the same as in the soil to which these materials were added in this study.

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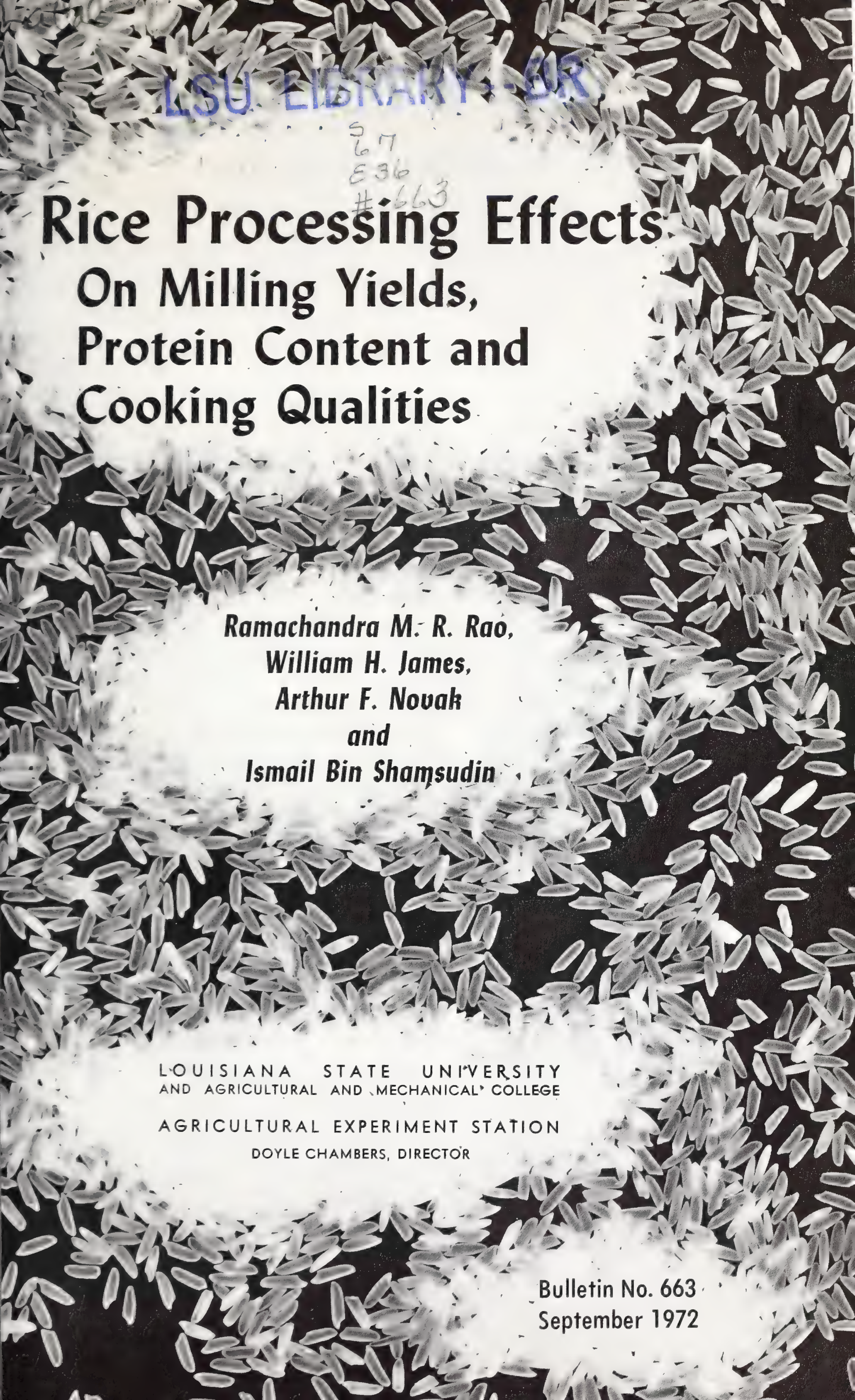

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Rice Processing Effects
On Milling Yields, Protein Content and Cooking Qualities

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Rice Processing Effects on Milling Yields, Protein Content and Cooking Qualities

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INTRODUCTION

Rice, which is the chief daily staple in the diet of more than half the world's population, is an important agricultural commodity in Louisiana. In the most densely populated areas of the tropics, rice is more than just a carbohydrate food; there it is also the chief source of dietary protein.

When harvested, the rice grain is encased in an easily removable protective hull or husk. Inside the hull is a kernel of brown rice, so-called because of the dark bran layers covering the endosperm. The kernel with part of the bran removed is called undermilled rice, and when practically all of the bran layers and germ are removed it is known as milled rice. Brown rice contains more protein, minerals, and vitamins than milled rice, but when large amounts are consumed daily, as is the custom in the Orient, it is reported to cause digestive disturbances (*27*).[2] Milled rice is more attractive in appearance, requires less time to cook, and keeps better in storage than brown and undermilled rice. Furthermore, in humid environments, both brown and undermilled rice easily become rancid (*17, 27*).

Rice as harvested in the fields is known as rough rice, or paddy. The rough rice is milled to remove the hull, bran, and germ with minimum breakage of the kernels. The milling process generally consists of four separate operations: (a) cleaning the field run rough rice to remove contaminants and other foreign materials; (b) shelling the cleaned rough rice to remove the hulls; (c) scouring the brown rice to remove the coarse outer layers of bran, aleurone layer, and germ; and (d) grading the mixture of whole and broken milled kernels according to size classes known as head rice, broken, screenings, and brewers rice (*38, 47, 53*). Highly milled rice is white to creamy in color. It is high in starch and is an excellent high energy food but is low in vitamins (*17*). Rough rice is often subjected to parboiling, which consists of processing with heat and water before the husks are removed. Parboiling makes it possible to utilize a lower grade of rice and produce a higher quality product with less breakage during milling. Parboiled rice retains vitamins and minerals during subsequent operations of milling, washing, and cooking. Among other advantages resulting from parboiling rough rice are greater ease in milling, resistance to insect and pest attack during storage, and better retention of shape during cooking (*53, 54*).

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[2] Italic numbers in parentheses refer to Bibliography, page 48.

Briefly, the parboiling process involves soaking the rough rice in either cold or hot water in cement or metal tanks for two to three days to increase the moisture content of the grain. The excess water is then drained off and the rice is placed in metal cylinders containing one or more perforated steam pipes. Steam is blown into the rice until the hulls are opened slightly. The parboiled rice is then removed from the cylinders, thoroughly dried in the sun or by artificial means, and milled. Several highly mechanized commercial parboiling processes have been developed in recent years (*12, 38*).

Parboiled rice differs from raw white rice in that the former possesses a light to dark yellow color and a distinctive "fermented" flavor and odor. The color, flavor, and odor are influenced by processing conditions. When produced under poorly controlled conditions, the flavor and color are strong, but under strict quality control the color may be very light and the flavor mild. The distinct color and flavor of parboiled rice is a deterrent for many who eat white rice, despite the high nutritive value of the parboiled product (*21*). Improvement in the quality would undoubtedly lead to greater consumption of parboiled rice.

Although the engineering and hygienic aspects of parboiling have received considerable attention in recent years, few comprehensive studies have been made on factors affecting the quality of parboiled milled rice. Earlier studies made on rice quality were limited mainly to specific processing conditions.

The objectives of the work described in this bulletin were to determine under controlled laboratory conditions the effects of variations of soaking temperature, soaking time, and steam temperature in the parboiling process on eight selected qualities and characteristics of milled rice.

LITERATURE REVIEW

Milling and Processing

Jones and Taylor in 1935 (*26*) investigated the effect of parboiling on long- and medium-grain commercial rice varieties grown in the United States. In this study the grains were soaked in water at room or controlled temperatures for the required length of time and steamed in a pressure cooker or in an autoclave with steam temperature at 122 ± 1°C. Samples soaked for 24 hours at room temperature and steamed for 15 or 25 minutes were reported to show increased yield of head rice for all varieties, with one exception. The increase in head rice, as a result of parboiling, was essentially the same regardless of the soaking period, the temperature of water in which the rice was soaked, or the time of steaming. It was also noted that the color and texture of the parboiled milled rice was affected by the soaking and steaming conditions.

Studies on 12 different parboiling and related treatments and their effects on the quality of long-, medium-, and short-grain varieties were made by Jones, Taylor, and Zeleny (*27*). It was shown that soaking rough rice for 24 hours resulted in excessive breakage in all varieties studied. Soaking in water at 96°C for 2.5 minutes with steaming at 15 lb. pressure for 15 minutes increased breakage in the short-grain variety, had no effect on the medium-grain, and improved the milling quality on the long-grain variety. All other treatments except one materially increased the yield of head rice. The average increase in head rice yield of the three varieties was 8% for the siddha, sela, and josh treatments and 28% for the other parboiling treatments.

The rice "conversion" process (*12*) and its influence on yield was studied by Kik (*35*). Rough rice was placed into large vessels under a vacuum of 25 inches of mercury for 10 minutes. Hot water (73°–85°C) under 80–100 lb. pressure was then introduced. The rice was soaked under this condition, with recirculation of the water, for periods ranging from 120 to 165 minutes. The water used in soaking was drained off and the soaked paddy was transferred into a large, steam-jacketed vessel, which was then partially evacuated. Dry steam was introduced for a short time. A vacuum of 28 to 29 inches of mercury was applied. The result showed that the average proportion of broken kernels of converted rice was 3.5% compared with 19.5% for the unconverted sample.

The breakage of rice during shelling was noted by Kik (*31*) during his investigations on thiamin loss during parboiling. Prolonged boiling reduced breakage from an average of 37.8% to 27.6% and subsequent steaming further reduced breakage to 6.8%.

Subrahmanyan et al. (*52*) suggested new procedures for production of improved quality parboiled rice in India. The procedure developed was similar to that adopted for the converted rice (*12, 35*). Instead of adding steam into a large amount of cold water, as in the conventional method (*53*), the water in the tank was heated to an initial temperature of 60° – 65°C by live steam and the paddy added after steaming. In the pilot study, it was reported that absorption of water for complete gelatinization of starch was decreased by three hours. When the soaked paddy was steamed for 5 – 10 minutes, the yield of head rice was the same by weight in comparison with commercial methods. It was also noted that the yields of head rice and breakage during milling of partially parboiled rice were intermediate between fully parboiled and raw samples.

Mecham et al. (*41*) studied yields of parboiled rice in relation to water uptake under different soaking conditions. These investigations showed differences among lots of rice in both water uptake and temperature requirements for adequate soaking. The total water requirements and the time needed for distribution of water within the kernel (to provide for gelatinization of the starch granules in the center of the kernel upon cooking) also differed. Soaking at temperatures much above 150°F caused some of the kernels to burst and the mass of the rice to become sticky and slimy because of starch gelatinization. In properly soaked rice, gelatinization of starch within the kernels was obtained by cooking for 5 minutes at 20 lb. pressure or 8 minutes at 10 lb. Results were also satisfactory with cooking at 30 or 40 lb. pressure for shorter times, but at these high pressures overcooking quickly caused the product to darken. Improper soaking and inadequate cooking resulted in incomplete gelatinization with a high proportion of broken kernels in the dried and milled product.

A comprehensive study of processing factors and their relationship to milling yields was made by Bhattacharya et al. (*6*). They reported that absorption of water by the paddy increased with temperature but was considerably below the gelatinization point. Beyond the gelatinization point the grain absorbed water rapidly, preferentially on surface layers, leading to early bursting and leaching. Milling quality depended on the severity of heat treatment during parboiling and the conditions of drying. The more severe the heat treatment, the better the treated rice was able to withstand the adverse drying. Other results reported by Bhattacharya were that insufficient soaking led to increased breakage; simple soaking of paddy at or above 70°C improved milling quality; and the rate of hydration of the paddy, as well as improvement in its milling yields by parboiling, showed varietal differences.

The results of the investigations performed at the International Rice Research Institute, Philippines, on the effect of parboiling on seven varieties of rice differing in amylose content have shown that the values of the breaking and crushing hardness, as measured with a Kuya-type tester, were higher for all parboiled samples than for the raw samples. The head rice yield at 4% bran was 99% of the total milled rice in all parboiled samples, whereas the average for the raw rice samples was 75.3%.

Craufurd (*15*) investigated effects of post-harvest sun drying, shade drying, and two artificial drying methods on yields of rice. He reported that these drying treatments did not affect milling yields. Sun drying, followed by parboiling and shade drying to 12% moisture content, gave 70% whole grain. Shade drying, followed by parboiling and shade drying to 12% moisture content, gave 60% whole grain. In a later study, Craufurd (*15*) noted that, in drying of rice, if the intensity of shade could be adjusted to keep the paddy temperature at 36 ± 1°C, serious loss of milling quality could be avoided.

Investigations by Bhattacharya (*9*) showed that parboiled paddy dried in the shade had excellent quality, but rapid drying with hot air (40°–80°C) or in the sun give high breakage. Two-staged drying with a tempering prior to attainment of the critical moisture content would also preserve milling quality. Tempering at higher moisture content, however, was less efficient, and multiple tempering gave no additional benefit. Drying in two phases, with a tempering in moisture range of 15% to 19% followed by hot conditioning after the final drying, was reported to give milling breakage not exceeding 2%.

Further investigation by Bhattacharya (*11*) showed that single-stage drying had no damaging effect on milling yields of rice until the moisture content had dropped below 16%. Hot storage for 3 hours following drying prevented or reduced, but did not eliminate, breakage. Two-staged drying, with tempering at 16% moisture, resulted in breakage no higher than that of the sun-dried control. Tempering at a slightly lower moisture content appeared to give slightly higher breakage.

The relationship between moisture content after drying, time of storage (tempering time), total rice yield, and percentage of brokens was reported by Sluyters (*51*). Neither the moisture content nor the storage time appeared to have an effect on the milled rice yield. At low moisture content the percentage of broken grain, expressed as the percentage of total rice yield, rose rapidly within three hours after drying. The lowest percentage of brokens occurred at 16% to 17% moisture.

Bhattacharya (*10*) investigated the relationship of kernel defects to breakage. He reported that cracks (whether inherent or freshly induced), immaturity, and chalkiness in the kernels were completely eliminated by parboiling. He concluded that parboiling was an excellent tool for salvaging paddy that contained a high proportion of immature kernels, or paddies that had been improperly harvested, improperly dried, or inadvertently damaged.

Jayanarayanan (*24*) investigated the effects of various processing conditions on the browning of parboiled rice. The investigation was concerned with the influence of steeping time and temperature, steaming pressure and time, pH of the steeping water, alpha-amylase activity, drying temperature, and sodium bisulfite concentration in the steeping water, on the discoloration or browning of parboiled rice. In the studies seven sets of parboiling experiments were designed to study each objective. From the results, he concluded that the steeping and steaming temperatures as well as the steeping and steaming times influenced browning or discoloration of parboiled rice. The pH of the steeping water was equally very important. It was found that raw rice amylases favored browning by the formation of reducing sugars during steeping.

Several highly mechanized parboiling processes were developed and introduced into the rice processing industry over the last two decades. The Avorio, Conversion, Yon-Malek, Fernandes, and Cristallo processes have been described in detail (*1, 12, 27, 44*). A review of these processes by Matz (*38*) indicated that yields of 66 to 71 pounds of total milled rice and 58 to 68 pounds of whole grain could be obtained from 100 pounds of starting rough rice.

Nutrients in Rice

Data on the composition of rice and rice products were published by Watt and Merrill (*56*) and McCall et al. (*39*). A comprehensive tabulation of compositional data for rice was compiled by Juliano (29) together with an extensive bibliography of articles from which the data were taken.

Summaries of the vitamin content of rices were compiled by F.A.O. (*17*), McCall and co-workers (*39*), Juliano (*29*), Kik (*34*), and Kik and Williams (*33*).

The protein content and the amino acid profiles of rice and rice products were reviewed by Houston and Kohler (*21*).

Studies by Juliano and co-workers (*28*) revealed that the protein content of rough, brown, and milled rice varied significantly among varieties. The Asian varieties were generally of lower protein content than those varieties planted in the United States, with one exception in the first crop and one exception in the second crop. They also observed a difference of about 4% in protein content of the same variety of rice planted at different seasons.

McCall et al. (*40*) investigated the influence of variety and environment on the physical and chemical composition of different rice varieties. They reported that both variety and environment had a highly significant influence on yields of milling and anatomical fractions of rough rice and the composition of true bran. Variety had a highly significant influence on the nitrogen content of white rice and the ash content of hulls. Environment had a highly significant influence on the ash content of hulls, and on the lipid, nitrogen, ash, and starch contents of the white rice.

Borasio and Gariboldi (*12*) made a comparative study of the protein contents of the Avorio and Cristallo processed rice. They reported a protein content of 6.30% for Avorio rice, 6.95% for Cristallo rice, and 6.10% for normal milled rice. It was pointed out that the improved chemical composition of milled parboiled rice was due to the decrease in removal of material during milling because of the hardness of the kernels.

Cagampang et al. (*13*) reported results of solubility studies on protein fractions of milled rice, bran, and rice polish of high and low protein samples. They showed that glutelin was the predominant fraction in the whole grain, milled product, and rice polish. Albumin and globulin were the major proteins of the bran and they were concentrated in the bran and polish, whereas prolamine was rather evenly distributed in all three fractions. They also pointed out that differences in the total protein content of the whole grain were due mainly to differences in glutelin content.

The influence of parboiling on the protein fractions was studied at the International Rice Research Institute (*21*). It was reported that parboiling had no effect on protein content but drastically reduced the extractability of protein, in all samples studied, by an average of 45%. The globulin fraction, however, showed the largest reduction, namely 65%.

Tamura and co-workers (*55*) reported the amino acid composition of the four main protein fractions of milled rice. They found high concentrations of lysine in albumin, of cystine in globulin, and of leucine and proline in prolamine.

Juliano and co-workers (*28*) found significant negative correlations between crude protein content and percentages of lysine, methionine, and threonine in a series of 16 rices. Positive correlations were found for tyrosine, arginine, and leucine.

Hunter, Ferrel, and Houston (*22*) reported results of a study on free amino acids in fresh and aged parboiled rice. Those in greatest initial concentration were alanine, aspartic acid, and glutamic acid. Those in intermediate concentration were arginine, asparagine, glycine, leucine, lysine, proline, serine, valine, and one unidentified ninhydrin-reacting compound. Those in the lowest concentration were cystine, histidine, methionine, phenylalanine, threonine, trytophan, and tyrosine. A significant loss of amino acids during accelerated storage, as indicated by the intensity of the amino acid spots, was also reported.

Aykroyd, Krishman, and Sundararajan (*3*) pointed out that machine-milled rice from raw rough rice contained 1.0 $\mu g/g$ of vitamin B_1. Machine-milled rice from parboiled rice contained 2.20 $\mu g/g$. Similarly, milled rice from raw rice had 16 $\mu g/g$ nicotinic acid, while milled rice from parboiled rice had 38 $\mu g/g$.

According to Kik et al. (*31*) rough rice or paddy had 3.0 $\mu g/g$ of B_1 and polished rice 0.6 $\mu g/g$, while rice bran had 21–31 $\mu g/g$. Later, Kik (*32*) reported that rice from the Conversion and Malekised processes showed greater retention of vitamin than untreated rice.

The distribution of thiamin in rice was discussed by Simpson (*50*). He confirmed that thiamin was largely centered in the scutellum but riboflavin was more uniformly distributed throughout the embryo.

Investigations on vitamin losses during parboiling and mechanical drying were made by Mitra and Chandhuri (*43*). Using Rupsal, Patnai, and Sitosal varieties grown in West Bengal, they reported that loss of vitamin was negligible. About 17–20% of thiamin was lost along with the bran on hulling.

Bhattacharaya and Rao (*8*) studied the effect of parboiling conditions on thiamin content of rice. They found that parboiling destroyed part of the total thiamin content of paddy. Soaking *per se* did not lead to loss, but much thiamin was leached out when the rough rice split during soaking. They reported that soaking at high pH also may reduce thiamin. The thiamin was protected against loss during milling by high temperature soaking or by soaking and steaming, but not by soaking alone at lower temperatures.

Rice Quality

Parthasarathi and Nath (*45*) studied water absorption by rice cooked for 30 minutes in excess water at different temperatures. The amount of water absorbed by the rice was taken as the criterion for the degree of cooking. Differences in water absorbed by different rice varieties were noted.

Rao et al. (*46*) recorded water absorption as swelling number, or the weight of water absorbed by rice when cooked in excess water at 98°C under standard conditions. They found a close association between the amylose content of rice and its swelling number. They reported that rice having a high swelling number was well liked by consumers because such rice was soft when cooked.

Halick and Kelly (*19*) reported water uptake at temperatures ranging from 72° to 82°C as important indicators of rice quality. Water uptake by whole rice at temperatures ranging from 72° to 82°C were closely related to gelatinization of starch in the rice kernel. They concluded that short- and medium-grain varieties with low gelatinization temperatures absorbed more water than did the long-grain varieties, with certain exceptions.

The water absorption value and the content of dissolved materials in the cooking water were used by Hogan and Plank (*20*) to evaluate 10 different varieties of milled rice. They reported that water uptake was greatest with short-grain, least with the long-grain, and intermediate with the medium-grain. Short-grain varieties gave the greatest amount of dissolved solids in the treating water while the long-grain varieties gave the least.

Batcher and co-workers (*4*) developed methods for measuring the water uptake, volume, residual starch, and total residual solids in cooking water. The tests indicated that the long-grain rice absorbed more water and when cooked had greater volume than the medium- or short-grain rices. There was less solid material in the residual cooking liquid obtained from long-grain rice than in the liquids associated with the other varieties tested. A significant correlation was observed between the water uptake ratio and cohesive score. Water uptake ratio and flavor were also highly significantly correlated.

In a later study Batcher et al. (*5*) evaluated 26 varieties of milled white rice. The long-grain varieties tended to absorb more water than the other grain types, although there were exceptions. They concluded that grain type appeared to be associated with water absorption but some overlapping occurred. Residual cooking liquids from most of the long-grain varieties had less total solids and starch than the liquids from short- and medium-grain varieties. However, Century Patna and Toro had greater amounts of total solids in residual cooking liquids than other long-grain varieties.

The use of a starch-iodine blue test as a quality indicator of white milled rice was investigated by Halick and co-workers (*18*). The intensity of the blue color produced by addition of the iodine solution was indicative of the amylose leached or diffused from the ground rice under the condition of the test. They obtained low readings with varieties known to be of superior quality, while varieties known to be of poor quality gave high readings. A good correlation was reported between results of this method and those of actual cooking tests.

Investigation by Warth and Darabsett (*57*) showed that different varieties of rice disintegrated in alkali solution in a consistent order. Kernel disintegration and gelatinization were complete in some varieties in 24 hours, but in others were incomplete after that time, as indicated by a diffused white area adjacent to the kernels.

Jones (*25*) reported an association between kernel disintegration in a 2.8% potassium hydroxide solution and the cooking quality of rice. He observed that the temperature during the time of disintegration affected the degree of degradation, but not all varieties responded similarly.

Little et al. (*37*) used a seven-point numerical scale for spreading and clearing of white milled rice kernels that had been in a 1.7% potassium hydroxide solution for 23 hours. They reported that slight to moderate spreading and clearing was characteristic of most of the long-grain varieties and a more severe degradation was associated with medium- and short-grain varieties. The values for spreading and for clearing were negatively correlated with the panel score for cohesiveness.

Roberts et al. (*48*) used expanded volume, color, and soluble starch as quality indicators of parboiled rice. They reported that severity of heat treatment during the parboiling process increased the degree of expansion of the dry milled rice, darkened the color, and increased the soluble starch content of the product. Steaming temperatures exhibited the greatest influence on all these factors.

Kurien and co-workers (*36*) used swelling rates and swelling ratios as measurements for the swelling quality of rice. Raw rice was cooked for 15–20 minutes, while parboiled rice was cooked for 20–40 minutes to attain a soft consistency. At that stage of cooking, they observed that the average length, breadth, volume, and weight of cooked parboiled grains were generally greater than the corresponding values for cooked raw rice.

Bhattacharya and Rao (*7*) studied the effect of processing conditions on cooking quality of parboiled rice. Water uptake, iodine blue value of the gruel, and solids in gruel were used as measurements of cooking characteristics. They reported that soaking affected the quality only above 60°C. The greater the severity of heat treatment during soaking and steaming, the lower the water uptake and the darker the color of the rice. Soaking at 70°C, and above, had a greater effect on the color of the rice, whereas steaming affected the cooking to a greater extent.

MATERIALS AND METHODS

Based upon practical considerations of the effects of temperature and length of time of soaking rice in heated water with subsequent steaming, three levels of water temperature during soaking—50°, 60°, and 70°C—together with five periods of elapsed time during soaking—3, 6, 9, 12, and 15 hours—were chosen for study in these experiments. These levels of temperature and periods of time yielded 15 different groups of soaked rice.

For each of these 15 groups, control samples consisting of only shelled and milled (or raw) rice were included in the study; also included were 15 samples representing the various soaked but unsteamed groups.

Three steam temperatures—100°, 110°, and 120°C—were selected for each of the 15 groups. These yielded 45 different kinds of parboiled rice, that is, rice that had been both soaked and steamed. Thus, 75 samples of rice consisting of 15 controls, 15 soaked but not steamed, and 45 samples of soaked and steamed products were obtained. Since all the operations were performed in replicate, a total of 150 batches of rice were prepared and used in studying the effects of various levels of water temperature during soaking, elapsed time during soaking, and steam temperature on eight characteristics of rice, namely, total yield of milled rice, percent of head rice in the milled product, color of milled rice, protein content of brown rice, protein content of milled rice, water uptake ratio of milled rice, volume of cooked milled rice, and residual solids in cooking water.

Each of the eight variables measured was evaluated according to a 5 × 3 × 5 factorial arrangement of treatments (5 kinds of group treatments which included 3 levels of steam temperature × 3 levels of temperature of the water in which the rough rice samples were soaked × 5 levels of elapsed time during soaking) in a randomized block design with 2 replicates. The data for each variable were subjected to a standard analysis of variance for a mixed model in which grouping of treatments was regarded as a fixed effect, and temperature of water during soaking and elapsed time during soaking were regarded as random effects.

Rice Samples

The rice used in this study was Dawn, a long-grain variety, planted at the Rice Experiment Station, Crowley, Louisiana, where in September 1970 it was harvested, cleaned, and dried to a moisture content of 12% in an L.S.U. type dryer. After being transported to the Baton Rouge campus, the rice was further cleaned in a clipper seed cleaning machine to remove the impurities and foreign materials that had escaped the primary cleaning operations. The cleaned rice was divided into two lots, Replicate I and Replicate II, each weighing about 40 kilograms. Each replicate lot was passed separately through a Boerner Sample Divider, one kilogram at a time. Seventy-five representative samples, each weighing 300 grams, were prepared from each of the two replicate lots, thus yielding a total of 150 samples, each of which was stored individually in a polyethylene bag. The two 75-sample replicate lots were kept separately in metal containers and were stored at room temperature for one month or less before being used.

Processing of Rough Rice

Each 300-gram sample, except the 15 raw controls, was placed in a one-liter beaker to which was added 750 milliliters of distilled water, pH 6.9. The beaker was placed in a constant-temperature water bath and the contents were stirred manually with a glass stirrer. After soaking at the appropriate temperature—50°, 60°, or 70°C—for the proper length of time—3, 6, 9, 12, or 15 hours—the sample was transferred onto an 8" × 8" metal screen and drained for 5 minutes to remove excess water. The metal screen and sample to be steamed were placed in an autoclave and subjected to the appropriate steam temperature—100°, 110°, or 120°C—for 10 minutes. Each steamed sample was spread on aluminum foil, 24" X 24", and allowed to dry at room temperature (about 25°C) for 48 hours, or less, until the moisture content was 12% as determined with a Motomco electric moisture tester. The dried samples were stored in polyethylene bags at room temperature until they were milled.

Milling and Grading

Exactly 150 grams of rice from each sample was taken and shelled in a McGill sheller to remove the hulls. The machine was set according to U.S.D.A. specifications for milling Southern long-grain rice (*47*). The samples of brown rice thus obtained were kept in polyethylene bags that were stored at 40°F until they were removed for polishing.

The polishing operation, or removal of the bran from the brown rice, was done in a Satake Testing Pearler, Model OM–2B. The milled rice thus obtained was weighed and the percent recovery or milling yield was computed, based on the original weight of the rough rice sample. The samples of milled rice were individually placed in polyethylene bags that were kept in metal containers stored at 40° F.

Brown rice samples for use in the Kjeldahl nitrogen determinations were obtained in each instance by shelling the portion of the 300-gram sample of rough rice that remained after removal of the 150-gram sample for processing. The 150 samples of brown rice thus obtained were stored at 40° F.

The milled rice samples were assayed for head rice by use of a Grain Sizing Device (*47*). Final separation of the broken kernels from the head rice was made manually, grain by grain. The head rice obtained from each sample of milled rice was weighed and the percentage of head rice in the milled rice, which is an index of quality, was computed. The samples of head rice were transferred into polyethylene bags and stored at 40° F prior to color, protein, and cooking tests.

Color Measurements

The color of the milled rice was measured by means of a Gardner Digital Color and Color Difference Meter, Model X–10, with L, a, and b scales. Only whole kernels were used in the determination. A 20-gram sample was put into a glass cuvette and placed on the aperture plate. The sample was read against a reference White Reflectance Standard No. 1093 (with L value 91.6, a_L value 1.3, and b_L value 0.1), supplied by the manufacturer. Each sample was read a number of times by pouring the samples and refilling at least three times. The average L, a_L, and b_L readings were recorded. The total color difference, E, between the standard and each of the specimens was computed by using the formula $E = \sqrt{\Delta_L{}^2 + \Delta a^2 + \Delta b^2}$ where Δ_L, Δa, and Δb are the respective differences between the sample and the standard.

Protein Analysis

Kjeldahl protein of brown and milled rice was determined according to the approved method of the A.O.A.C. (*2*).

Moisture Determination

Moisture content of milled and brown rice was determined by A.O.A.C. (*2*) approved method.

Cooking Tests

Cooking tests were conducted according to the method of Batcher et al. (*4*), Bhattacharya and Rao (*7*), and Roberts et al. (*48*) with certain modifications. Three basic characteristics were determined, namely, water uptake ratio, volume of cooked rice, and total solids in the residual cooking liquid (TSRCL). Numerical values for these three attributes were obtained in sequence, using one weighed sample of milled rice. A total of 150 5-gram samples of milled rice were individually cooked in wide glass tubes containing 50 milliliters of distilled water. The glass tubes were immersed for 20 minutes in a beaker of boiling water that was heated on an electric hot plate. Each sample of cooked rice was drained on a sieve, and after the excess moisture had been quickly blotted with filter paper, the cooked rice was weighed to obtain the water uptake ratio, that is, the number of grams of water absorbed per gram of rice. Immediately after the weighing operation, the volume of the cooked rice was determined by the water displacement method. Solids in the residual cooking liquid were determined by evaporating the cooking water to dryness in a tared 25-ml glass beaker in an oven at 100°C for 24 hours. The weight of the residual solids was divided by the weight of the raw sample and the results were recorded as milligrams of TSRCL per gram of rice.

RESULTS AND DISCUSSION

Results of the analysis of variance for the eight sets of data are presented in Table 1. The four sources of variation in the experiments affected the eight characteristics of milled rice as follows:

(1) Small, but significant, differences between the two replicate experiments existed for: total yield of milled rice, head rice yield, water uptake ratio, volume of cooked rice, and residual solids in cooking water. Unaffected by replication were: color of milled rice and protein content of brown and milled rice.

(2) Significantly associated with elevating the temperature of the soaking water were: increased total yield of milled rice, darkened color, and reduced values for water uptake ratio, volume of cooked rice, and residual solids in cooking water. Head rice yield and protein content of brown and milled rice were not affected by soaking temperatures.

(3) Significantly associated with increased lengths of soaking time were: increased yields of head rice, darkened color, and reduced values for water uptake ratio and volume of cooked rice. Not affected by soaking time were: total yield of milled rice, protein content of brown or milled rice, and residual solids in cooking water.

(4) The soaking and steaming operations did not affect the protein content of brown or milled rice. The steaming operation was significantly associated with: increased total yield of milled rice, increased yield of head rice, darkened color, and reduced values for water uptake ratio, volume of cooked rice, and residual solids in cooking water.

Total Yields of Milled Rice

The mean percentages for total yields of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 2.

TABLE 1.—ANALYSIS OF VARIANCE FOR EIGHT VARIABLES OF PARBOILED *DAWN* RICE

SOURCE OF VARIATION	d.f.	MEAN SQUARES							
		PERCENT YIELDS			PERCENT PROTEIN		COOKING QUALITIES		
		Milled from Rough	Head Rice in Milled	COLOR	In Brown Rice	In Milled Rice	Water Uptake Ratio	Volume Cooked Milled Rice	Residual Solids in Cooking Water
Total	149								
R—Replicate	1	6.76**	91.49**	0.003	0.0129	0.0091	0.082*	1.57*	1.36**
A—Grouping (fixed effect)	4	307.70**	4046.15**	2048.89**	0.0189	0.0346	3.594**	101.93**	13.14**
B—Soak. Temp. (random effect)	2	2.64*	214.27	203.20**	0.0998	0.0228	0.416**	6.95**	2.32*
C—Soak. Time (random effect)	4	1.25	445.90*	65.77**	0.0377	0.0906	0.101**	2.18**	0.36
AB—Grouping × Soak. Temp.	8	0.35	62.66**	15.68**	0.0461	0.0969*	0.191**	3.06**	0.48*
AC—Grouping × Soak. Time	16	0.46	56.95**	6.48**	0.0713	0.0479	0.023	0.90**	0.25
BC—Soak. Temp. × Soak. Time	8	1.53	71.34**	1.69**	0.0647	0.0476	0.016	0.12	0.40**
ABC—Grouping × Soak. Temp. × Soak. Time	32	1.28*	16.87*	1.75**	0.0962*	0.0238	0.009	0.29	0.17*
Error	74	0.77	9.45	0.29	0.0599	0.0431	0.017	0.34	0.09

$^{**}p<0.01$
$^{*}p<0.05$

TABLE 2.—MEAN PERCENTAGES FOR TOTAL YIELDS OF MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE
Soaking		Group Treatment					B×C (Temp.×Time)
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	65.33	62.90	70.27	71.52	70.72	68.15
	6	65.95	64.50	72.32	71.50	70.44	68.94
	9	65.40	65.94	71.54	71.30	71.42	69.12
	12	64.50	67.35	71.08	71.48	71.82	69.25
	15	65.75	67.12	72.03	71.92	71.44	69.65
60°	3	65.33	66.62	70.93	71.10	71.14	69.02
	6	66.02	65.64	71.33	71.08	71.28	69.07
	9	65.85	65.54	71.39	71.21	71.54	69.11
	12	66.21	65.23	71.64	71.77	71.37	69.24
	15	65.88	64.78	71.66	70.76	71.92	69.00
70°	3	66.10	66.60	71.25	71.23	71.80	69.40
	6	66.00	67.55	72.98	71.56	71.96	70.01
	9	66.23	64.52	71.16	71.76	72.02	69.14
	12	66.10	65.32	71.84	71.96	72.04	69.45
	15	65.02	65.06	71.89	72.22	72.04	69.25
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	65.59	65.37	70.82	71.29	71.22	68.86
	6	65.99	65.90	72.21	71.38	71.23	69.34
	9	65.83	65.33	71.36	71.42	71.66	69.12
	12	65.60	65.96	71.52	71.74	71.74	69.31
	15	65.55	65.66	71.86	71.64	71.80	69.30
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	65.39	65.56	71.45	71.54	71.17	69.02
	60°	65.86	65.56	71.39	71.18	71.45	69.09
	70°	65.89	65.81	71.82	71.75	71.97	69.45
GROUP MEANS A		65.71	65.64	71.55	71.49	71.53	OVERALL MEAN 69.19

For Replicate I the mean value was 68.97%, whereas for Replicate II it was 69.40%. The difference between the means of the two replicates, 0.43%, although small, was highly significant ($p < 0.01$).

The processing treatments to which the five groups of rough rice samples were subjected very significantly ($p < 0.01$) affected the total yield of milled rice. The mean total yields associated with the five treatments were: raw (untreated), 65.71%; soaked but not steamed, 65.64%; and for those samples steamed at 100°, 110°, and 120°C, the yields were 71.55, 71.49, and 71.53%, respectively.

The temperature of the water during soaking significantly affected ($p < 0.05$) the total yield of milled rice obtained from the treated rough rice. The highest temperature of the water during soaking was associated with the highest yield. For rice soaked in water at 50°C the mean yield of milled rice was 69.02%; at 60°C it was 69.09%; and at 70°C it was 69.45%.

Increasing the length of time that the rough rice was soaked in hot water prior to milling had no significant effect ($p > 0.05$) on the mean total yields. The five periods of time during which the rough rice was soaked, namely, 3, 6, 9, 12, and 15 hours, were associated respectively with the following total yields of milled rice: 68.86, 69.34, 69.12, 69.31, and 69.30%.

All three bivariate interactions, A × B, A× C, and B × C, for total yields of milled rice were not significant ($p > 0.05$). This indicates that, with respect to mean total yields of milled rice, relationships between groups of samples × water temperature during soaking, between groups of samples × elapsed time during soaking, and between water temperature during soaking × elapsed time during soaking were consistent for all batches of treated rice.

In the A × B interaction, groups of samples × water temperature during soaking, the lowest yields of milled rice were associated with the lowest soaking temperature, 50°C, and the absence of steam treatment, whereas the best yields were associated with the highest soaking temperature, 70°C, and treatment with steam.

In the A × C interaction, groups of samples × elapsed time during soaking, the mean total yields for the two unsteamed groups ranged from 65.33% to 65.99%; among the three steamed groups the total yields ranged from 70.82% to 72.21%. These values indicate that treating the soaked rice with steam, whether at 100°, 110°, or 120°C, increased the yield of milled rice about 6%, based on the weights of the rough rice samples; furthermore, these relationships were not affected by the length of time the samples were soaked prior to being steamed.

In the B × C interaction, water temperature during soaking × elapsed time during soaking, the mean total yields of milled rice associated with a soaking temperature of 50°C increased slightly from 68.15% to 69.65% as the soaking time increased from 3 hours to 15 hours; a similar but less definite trend was apparent when the rough rice was soaked in water at 60° or 70°C.

In the trivariate interaction, A × B × C, the mean yields among the 30 samples of the two unsteamed groups ranged from 62.90% to 67.55%. These values were associated with samples of rough rice that had been soaked at 50° and 70°C for 3 and 6 hours, respectively. The mean percentages for the other 45 samples in the three steamed groups ranged from 70.27% to 72.98%; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value, also from samples steamed at 100°C, was associated with 70°C as the temperature of the water in which it was soaked, and 6 hours as the period of soaking time. The trivariate interaction for total yields of milled rice was significant ($p < 0.05$). This indicates that, with respect to the mean percentages of total milled rice obtained from the rough rice samples, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Yields of Head Rice

The mean percentages for yields of head rice, based on the weights of the corresponding samples of milled rice, for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, $A \times B$, $A \times C$, and $B \times C$; and the trivariate interaction, $A \times B \times C$, together with the overall mean are given in Table 3.

The mean yields of head rice for Replicates I and II were 80.91 and 82.48%, respectively. The difference between the two means, 1.57%, was highly significant ($p < 0.01$). Replicate II not only gave a significantly greater mean total yield of milled rice, as was noted in the preceding section, but also contained a significatly larger proportion of head rice in the milled product than did Replicate I. The significant difference in yields suggests that the degree to which the samples in Replicate II were milled was slightly less than that to which those in Replicate I were milled.

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the proportions of head rice in the milled product. The mean percentages of head rice associated with the five treatments were: raw, 75.18%; soaked but not steamed, 64.42%; and for those steamed at 100°, 110°, and 120°C, the yields were 87.14, 90.31, and 91.42%, respectively. These values indicate that the effect of soaking rough rice in hot water was to reduce the proportion of head rice in the milled product by nearly 11%. The effect of treating the soaked rice with steam was to increase substantially the proportion of head rice in the milled product due to the gelatinization and hardening of the kernels during the steaming process. The highest steaming temperature, 120°C, was associated with the highest yield of head rice.

Increasing the temperature of the water in which the rough rice was soaked from 50°C, or from 60°C, to 70°C tended to increase the proportion of head rice in the milled product but this effect was not statistically significant ($p > 0.05$). Mean yields of 80.31, 80.70, and 84.08% for head rice were associated respectively with soaking temperatures of 50°, 60°, and 70°C.

Increasing the length of time from 3 hours to 9 hours that the rough rice samples were soaked in hot water significantly increased ($p < 0.05$) the proportion of head rice in the milled product from 75.22% to 84.35%, but the mean percentages of head rice, 83.86% and 84.00%,

TABLE 3.—MEAN PERCENTAGES FOR HEAD RICE IN MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	75.41	62.08	63.44	70.03	75.55	69.30
	6	74.70	63.22	84.88	88.40	85.70	79.38
	9	74.20	74.97	92.29	92.69	92.78	85.38
	12	74.36	64.17	90.70	92.27	92.94	82.89
	15	75.10	70.25	92.77	92.76	92.14	84.60
60°	3	75.28	58.68	73.10	82.69	86.79	75.31
	6	75.30	60.14	81.95	88.04	91.14	79.32
	9	75.55	60.92	87.15	91.02	93.74	81.68
	12	76.10	64.82	90.80	93.24	93.97	83.78
	15	75.12	62.87	91.57	93.26	94.26	83.42
70°	3	75.82	59.14	85.26	92.07	92.90	81.04
	6	74.70	69.84	91.12	92.91	93.69	84.45
	9	76.05	69.30	93.76	94.70	96.07	85.98
	12	74.88	66.62	94.28	94.33	94.49	84.92
	15	75.20	59.26	94.00	96.29	95.21	83.99
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	75.50	59.96	73.94	81.60	85.08	75.22
	6	74.90	64.40	85.98	89.78	90.18	81.05
	9	75.27	68.40	91.07	92.80	94.20	84.35
	12	75.11	65.20	91.93	93.28	93.80	83.86
	15	75.14	64.12	92.78	94.10	93.87	84.00
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	74.75	66.94	84.82	87.23	87.82	80.31
	60°	75.47	61.48	84.91	89.65	91.98	80.70
	70°	75.33	64.83	91.68	94.06	94.47	84.08
GROUP MEANS A		75.18	64.42	87.14	90.31	91.42	OVERALL MEAN 81.70

which were associated respectively with the 12-hour and 15-hour periods of soaking were slightly less than the value of 84.35% which was associated with the 9-hour soaking period.

All three bivariate interactions, A × B, A × C, and B × C, for mean percentages of head rice in milled rice were highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples was associated with mean percentages of about 75% head rice in the milled product. The lowest yields of head rice, 61.48, 64.83, and 66.94%, were associated with unsteamed rice that had been soaked in water at 60°, 70°, and 50°C, respectively. Among the three steamed groups the mean proportions of head rice in the milled product ranged from

84.82% to 94.47%. These values indicate that treating the soaked rice with steam very substantially increased yields of head rice, with the greatest increases being associated with 70°C as the soaking temperature and 120°C as the steaming temperature. Statistically, the A × B interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean percentages of head rice in the milled product, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, as in the A × B interaction, the group of untreated rough rice samples was associated with mean percentages of about 75% head rice in the milled product. The mean values for the samples that had been soaked in hot water but not steamed ranged from 59.96%, which was associated with a 3-hour period of soaking, to 68.40%, which was associated with a 9-hour period of soaking. Among the three steamed groups the mean proportions of head rice in the milled product ranged from 73.94% to 94.20%; the smaller value was associated with a 3-hour period of soaking and steaming at 100°C, whereas the larger value was associated with a 9-hour period of soaking and steaming at 120°C. Statistically, the A × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean percentages of head rice, the relationship between groups of samples × elapsed time during soaking was not consistently maintained for all batches of rice.

In the B × C interaction, increased proportions of head rice in the milled product were associated with increasing the soaking temperature from 50° to 60°C, or from 60° to 70°C, for soaking periods of 3, 6, or 9 hours. After the samples had been soaked for 9 hours, whether the water temperature during soaking was 50°, 60°, or 70°C, further extension of the soaking period to 12 or 15 hours usually had a slightly adverse effect on the yield of head rice. The smallest mean value, 69.30%, of head rice was associated with samples that had been soaked for 3 hours in water at 50°C; the largest mean value, 85.98%, was associated with samples that had been soaked for 9 hours in water at 70°C. Statistically, the B × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean percentages for yields of head rice, the relationship between water temperature during soaking × elapsed time during soaking was not consistent for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with head rice yields that ranged from 74.20% to 76.10%, with the overall mean for this group being 75.18%. The mean yields for the samples that had been soaked in hot water but not steamed ranged from 58.68%, which was associated with 3 hours of soaking in water at 60°C, to 74.97%, which was associated with 9 hours of soaking at 50°C. Values between these two extremes fluctuated in an erratic manner with respect to lengths of soaking periods and temperatures of soaking water. For the 45 steamed samples the mean percentages of head rice in the milled product ranged from 63.44% to 96.29%; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 110°C. In general, increasing the temperature of the steam treatment, or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, often tended to increase the mean percentages of head rice in the milled product. The trivariate interaction for mean percentages of head rice in milled rice was significant ($p < 0.05$). This indicates that, with respect to the mean percentages of head rice in the milled product, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Color of Milled Rice

Each of the individual measurements, from which were computed the means for the total color difference values of milled rice, represented the magnitude of the total color differences between the standard and the sample. These values, however, give no indication of the character of the color difference because the relative quantity and direction of lightness, hue, and saturation differences are not indicated.

The means for total color difference values of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, $A \times B$, $A \times C$, and $B \times C$; and the trivariate interaction, $A \times B \times C$, along with the overall mean are given in Table 4.

The mean value for total color difference associated with Replicate I was 31.71, which is virtually identical with the value, 31.72, which was associated with Replicate II.

The different group treatments to which the rough rice samples were subjected greatly influenced ($p < 0.01$) the color of the milled product. The mean color values associated with the different groups were: raw, 21.37; soaked but not steamed, 25.05; and for those steamed at 100°, 110°, and 120°C, the values were 33.82, 37.35, and 40.97, respectively. Soaking the rice samples in hot water darkened the milled product. The effect of steaming was to darken the product further, with the mean color values increasing about 3.5 units for each 10-degree rise in steam temperature.

Increasing the temperature of the water in which the rough rice was soaked increased very significantly ($p < 0.01$) the mean values for total color difference. For water temperatures of 50°, 60°, and 70°C during soaking, the associated mean color values were 29.62, 31.87, and 33.65, respectively.

Increasing the length of time from 3 hours to 12 hours that the

TABLE 4.—MEAN COLOR VALUES OF MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	21.00	20.27	27.98	31.88	36.70	27.57
	6	21.10	20.38	31.22	33.12	38.18	28.80
	9	21.44	20.50	31.50	33.36	38.46	29.05
	12	20.60	23.24	34.44	36.92	40.15	31.07
	15	21.43	23.42	34.71	37.32	41.28	31.63
60°	3	20.98	23.88	29.69	34.10	40.08	29.75
	6	21.54	22.74	32.68	38.45	40.90	31.26
	9	20.40	25.16	32.89	39.96	42.12	32.11
	12	21.44	27.00	35.92	39.10	42.10	33.11
	15	21.95	25.92	35.88	40.19	41.56	33.10
70°	3	21.60	25.56	31.14	37.33	41.20	31.36
	6	21.64	29.42	35.47	38.06	41.54	33.22
	9	21.82	29.78	37.05	39.10	42.60	34.07
	12	21.96	31.17	37.88	40.97	43.18	35.03
	15	21.71	27.28	38.88	40.34	44.50	34.54
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	21.19	23.24	29.60	34.44	39.33	29.56
	6	21.42	24.18	33.12	36.54	40.20	31.10
	9	21.22	25.15	33.81	37.48	41.06	31.74
	12	21.33	27.14	36.08	39.00	41.81	33.07
	15	21.70	25.54	36.49	39.28	42.44	33.09
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	21.11	21.56	31.97	34.52	38.95	29.62
	60°	21.26	24.94	33.42	38.36	41.35	31.87
	70°	21.75	28.64	36.08	39.16	42.60	33.65
GROUP MEANS A		21.37	25.05	33.82	37.35	40.97	OVERALL MEAN 31.71

rough rice samples were soaked in hot water very significantly ($p < 0.01$) darkened the color of the milled product. Extending the period of soaking from 12 to 15 hours had a negligible effect on the mean color value. For the different periods of soaking time, namely, 3, 6, 9, 12, and 15 hours, the associated mean total color difference values were 29.56, 31.10, 31.74, 33.07, and 33.09, respectively.

All three bivariate interactions, A × B, A × C, and B × C, for mean total color difference values of milled rice were highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples had the least color; the values ranged from 21.11 to 21.75. The unsteamed rice samples that had been soaked in water at 50°, 60°, and 70°C were associated with mean color values of 21.56, 24.94, and 28.64, respectively. Among the three steamed groups the values ranged from 31.97 to 42.60. These values indicate that treatment of the soaked rice with steam appreciably darkened the color of the milled product, with the greatest darkening being associated with 70°C as the soaking temperature and 120°C as the steam temperature. Statistically, the A × B interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice samples.

In the A × C interaction, the group of untreated rough rice samples gave the lowest color difference values, which ranged from 21.19 to 21.70. The mean values for the samples that had been soaked in hot water but not steamed ranged from 23.24, which was associated with 3 hours of soaking, to 27.14, which was associated with 12 hours of soaking. Associated with 15 hours of soaking was an intermediate value, 25.54. Among the three steamed groups, increasing either the length of the soaking period or the steam temperature increasingly darkened the milled product, the mean color values of which ranged from 29.60 to 42.44; the smaller value was associated with 3 hours of soaking and 100°C as the steam temperature, whereas the larger value was associated with 15 hours of soaking and 120°C as the steam temperature. Statistically, the A × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between groups of samples × elapsed time during soaking was not consistently maintained for all batches of rice samples.

In the B × C interaction, increasing the temperature of the water in which the rough rice was soaked, or increasing the length of time the rice was soaked, with two exceptions, darkened the color of the milled product, the mean values of which ranged from 27.57, which was associated with 3 hours of soaking at 50°C, to 35.03, which was associated with 12 hours of soaking at 70°C. Extending the period of soaking from 12 to 15 hours at 60°C had a negligible effect on color, and soaking at 70°C for 15 hours was associated with a mean color value of 34.54, which was 0.49 unit less than the value associated with 12 hours of soaking at 70°C. Statistically, the B × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationship between water temperature during soaking × elapsed time during soaking was not consistently maintained for all batches of rice samples.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean color values that ranged from 20.40 to 21.96, with the overall mean for the group being 21.37. The mean color values for the samples that had been soaked in hot water but not steamed ranged from 20.27 to 31.17; the smaller value was associated with 3 hours of soaking at 50°C, whereas the larger value was associated with 12 hours of soaking at 70°C. Values between these two extremes fluctuated, particularly with respect to lengths of soaking periods at 60°C. For the 45 steamed samples the mean values for the total color difference of the milled product ranged from 27.98 to 44.50; the smaller value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 120°C. In general, increasing the temperature of the steam treatment or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, tended to darken the milled product. Statistically, the trivariate interaction was highly significant ($p < 0.01$). This indicates that, with respect to the mean values of total color difference, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice samples.

Protein Content of Brown Rice

The mean percentages for protein content of brown rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, together with the overall mean are given in Table 5.

The values for protein content among the 150 individual samples of brown rice ranged from 7.11% to 8.90%, with the overall mean being 8.23%. The mean percentage value for Replicate I was 8.24%; that for Replicate II was 8.22%. The difference between the two values was not significant ($p > 0.05$).

The processing treatments to which the five groups of rough rice samples were subjected did not significantly affect ($p > 0.05$) the protein content of brown rice. The mean values associated with the five treatments were: raw, 8.25%; soaked but not steamed, 8.19%; and for those steamed at 100°, 110°, and 120°C the values were 8.25, 8.21, and 8.22%, respectively.

The temperature of the water during soaking did not significantly affect ($p > 0.05$) the protein content of brown rice. Mean values of 8.18, 8.23, and 8.27% were associated with soaking temperatures of 50°, 60°, and 70°C, respectively.

Increasing the length of time that the rough rice samples were soaked in hot water had no significant effect ($p > 0.05$) on the protein content of brown rice. Associated with 3, 6, 9, 12, and 15 hours of soaking the rough rice samples in hot water were respectively the following mean values for protein in brown rice: 8.22, 8.21, 8.25, 8.27, and 8.18%.

These results indicate that neither replication, differences in group

TABLE 5.—MEAN PERCENTAGES OF PROTEIN IN BROWN RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	8.20	8.04	8.14	8.02	8.15	8.11
	6	8.24	8.18	8.38	7.99	8.44	8.25
	9	8.18	8.14	8.16	8.44	8.18	8.22
	12	8.29	8.11	8.05	8.58	7.72	8.15
	15	8.21	8.22	8.42	7.80	8.21	8.17
60°	3	8.38	8.20	8.10	8.04	8.29	8.20
	6	8.37	8.15	8.27	7.70	8.12	8.12
	9	8.23	8.24	8.14	8.13	8.42	8.23
	12	8.44	8.69	7.98	8.50	8.38	8.40
	15	8.23	7.86	8.44	8.30	8.12	8.19
70°	3	8.40	8.34	8.40	8.27	8.28	8.34
	6	8.12	8.36	8.34	8.42	8.06	8.26
	9	8.24	8.20	8.38	8.48	8.16	8.29
	12	8.13	8.10	8.62	8.31	8.22	8.28
	15	8.14	8.08	7.90	8.17	8.64	8.19
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	8.33	8.19	8.21	8.11	8.24	8.22
	6	8.24	8.23	8.33	8.04	8.21	8.21
	9	8.22	8.19	8.23	8.35	8.25	8.25
	12	8.29	8.30	8.22	8.46	8.10	8.27
	15	8.20	8.06	8.25	8.09	8.32	8.18
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	8.23	8.14	8.23	8.17	8.14	8.18
	60°	8.33	8.23	8.19	8.15	8.27	8.23
	70°	8.20	8.22	8.33	8.33	8.27	8.27
GROUP MEANS A		8.25	8.19	8.25	8.21	8.22	OVERALL MEAN 8.23

treatment, water temperature during soaking, nor elapsed time during soaking, affected the protein content of brown rice.

All three bivariate interactions, A × B, A × C, and B × C, for mean percentages of protein in brown rice were not significant ($p > 0.05$). This indicates that, with respect to mean values for protein in brown rice, relationships between groups of samples × water temperature during soaking, between groups of samples × elapsed time during soaking, and between water temperature during soaking × elapsed time during soaking were consistent for all batches of rice.

The corresponding trivariate interaction, A × B × C, was significant ($p < 0.05$). Among the 75 mean percentages, the values ranged from

7.70% to 8.64%; the smaller value was associated with samples of rough rice that had been soaked in water at 60°C for 6 hours and then steamed at 110°C, whereas the larger value was associated with 15 hours of soaking at 70°C followed by steam treatment at 120°C. Between 7.70% and 8.64%, the values fluctuated in an erratic manner. Fluctuations were least in the group of raw samples, where the values ranged from 8.12% to 8.44%. The largest fluctuations, ranging from 7.72% to 8.64%, occurred in the group of samples that had been steamed at 120°C. This indicates that, with respect to mean percentages of protein in brown rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Protein Content of Milled Rice

The mean percentages for protein content of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 6.

The values for protein content among the 150 individual samples of milled rice ranged from 6.17% to 7.41%, with the overall mean being 7.12%, which is 1.11% less than 8.23%, the corresponding overall mean for protein content of brown rice. These values indicate that 13.5% of the protein in brown rice was removed in the milling operation.

The mean percentage of protein in milled rice for Replicate I was 7.11%; that for Replicate II was 7.13%. The difference between the two values was not significant ($p > 0.05$).

The processing treatments to which the five groups of rough rice samples were subjected had no significant effect ($p > 0.05$) on the protein content of milled rice. The mean values associated with the five treatments were: raw, 7.10%; soaked but not steamed, 7.09%; and for those steamed at 100°, 110°, and 120°C the values were 7.09, 7.16, and 7.15%, respectively.

The temperature of the water during soaking did not significantly affect ($p > 0.05$) the protein content of milled rice. Mean values of 7.13, 7.09, and 7.14% were associated with soaking temperatures of 50°, 60°, and 70°C, respectively.

Increasing the length of time that the rough rice samples were soaked in hot water had no significant effect ($p > 0.05$) on the protein content of milled rice. Associated with 3, 6, 9, 12, and 15 hours of soaking the rough rice samples in hot water were respectively the following mean values for protein in milled rice: 7.21, 7.11, 7.08, 7.10, and 7.08%.

These results indicate that neither replication, differences in group treatment, water temperature during soaking, nor elapsed time during soaking, affected the protein content of milled rice.

TABLE 6.—MEAN PERCENTAGES OF PROTEIN IN MILLED RICE

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	7.32	7.36	7.16	7.27	7.20	7.26
	6	6.94	7.08	7.04	7.11	7.12	7.06
	9	7.02	6.64	7.15	7.14	7.18	7.03
	12	6.72	6.91	7.29	7.31	7.24	7.09
	15	7.16	7.14	7.04	7.28	7.32	7.18
60°	3	7.19	7.26	7.07	7.06	7.22	7.16
	6	7.18	7.22	6.88	7.04	7.23	7.11
	9	7.07	7.16	7.16	7.13	7.06	7.12
	12	6.95	7.20	7.04	6.97	7.00	7.03
	15	7.16	7.18	7.08	6.72	7.12	7.05
70°	3	7.24	7.11	7.11	7.36	7.26	7.22
	6	7.16	7.19	7.04	7.24	7.24	7.18
	9	7.09	6.90	7.08	7.20	7.19	7.10
	12	7.08	7.14	7.24	7.30	7.14	7.18
	15	7.24	6.90	6.91	7.20	6.80	7.01
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	7.25	7.24	7.12	7.23	7.23	7.21
	6	7.10	7.16	6.99	7.13	7.20	7.11
	9	7.06	6.90	7.13	7.16	7.14	7.08
	12	6.92	7.08	7.19	7.19	7.12	7.10
	15	7.19	7.07	7.01	7.06	7.08	7.09
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	7.03	7.02	7.14	7.22	7.21	7.13
	60°	7.11	7.21	7.04	6.98	7.13	7.09
	70°	7.16	7.05	7.08	7.26	7.13	7.14
GROUP MEANS A		7.10	7.09	7.09	7.16	7.15	OVERALL MEAN 7.12

Of the three bivariate interactions, A × B, A × C, and B × C, only the A × B interaction, groups of samples × water temperature during soaking, was significant ($p < 0.05$). No two of the five groups of samples were alike with respect to the effects of increasing the water temperature during soaking on the protein content of milled rice. This indicates that, with respect to mean percentages of protein in milled rice, the relationship between groups of samples × water temperature during soaking was not consistent for all batches of rice.

The trivariate interaction, A × B × C, was not significant ($p > 0.05$). Among the 75 mean percentages the values ranged from 6.64% to 7.36%; the smaller value was associated with unsteamed samples of rough rice that had been soaked in water for 9 hours at 50°C, whereas the larger value was associated with each of two treatments, (1) unsteamed samples that had been soaked for 3 hours in water at 50°C, and (2) samples that had been soaked for 3 hours in water at 70°C and then steamed at 110°C. Fluctuations in mean values within each of the five groups ranged as follows: raw, 6.72% – 7.32%; soaked but not steamed, 6.64% – 7.36%; and for the groups steamed at 100°, 110°, and 120°C the ranges were 6.88% – 7.29%, 6.72% – 7.36%, and 6.80% – 7.32%, respectively. This indicates that, with respect to mean percentages of protein in milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistent for all batches of rice.

Water Uptake Ratio

The mean values for water uptake ratios of milled rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, together with the overall mean are given in Table 7.

Among the 150 individual samples of milled rice the water uptake ratios ranged from 3.03 to 4.48, with the overall mean being 3.83. For Replicate I the mean value was 3.81; for Replicate II, 3.86. The small difference between these two means was significant ($p < 0.05$) and represented 0.05 gram of water, which corresponded to a difference of 1.8% in water content. Replicate II, as was noted in a preceding section, in comparison with Replicate I contained 1.57% more head rice in the milled product, which may account for its larger mean water uptake ratio.

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the water uptake ratios of milled rice. The mean values associated with the five treatments were: raw, 4.20; soaked but not steamed, 4.12; and for the samples steamed at 100°, 110°, and 120°C, the values were 3.84, 3.64, and 3.36, respectively. These values indicate that the soaking operation reduced the water absorption capacity of milled rice 4.3%, based on the capacity of untreated rice. Increasing the temperature of the steaming process was associated with a further reduction in water absorption capacity. The greatest reduction, corresponding to a decrease of 27.6%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a very significant effect ($p < 0.01$) on the amounts of water that were absorbed by the milled rice during cooking. Mean water uptake ratios of 3.93, 3.81, and 3.75 were associated with soaking temperatures of 50°, 60°, and 70°C, respectively. These values indicate that the 10-degree rise in temperature from 50° to 60°C was

TABLE 7.—MEANS OF WATER UPTAKE RATIOS OF MILLED RICE
(Grams of cooked rice/gram of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C (Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	4.34	4.26	4.12	4.22	3.36	4.06
	6	4.26	4.16	4.14	3.88	3.32	3.95
	9	4.36	4.14	4.11	3.82	3.26	3.94
	12	4.15	4.10	4.06	3.81	3.21	3.86
	15	4.05	4.08	4.00	3.82	3.24	3.84
60°	3	4.24	4.10	3.86	3.72	3.47	3.88
	6	4.19	4.08	3.80	3.49	3.41	3.79
	9	4.19	4.06	3.73	3.50	3.52	3.80
	12	4.21	4.20	3.72	3.55	3.47	3.83
	15	4.15	4.20	3.70	3.34	3.46	3.77
70°	3	4.19	4.07	3.91	3.62	3.43	3.84
	6	4.12	4.01	3.72	3.46	3.28	3.72
	9	4.26	4.08	3.72	3.45	3.32	3.77
	12	4.16	4.17	3.36	3.40	3.30	3.68
	15	4.16	4.12	3.62	3.42	3.42	3.75
BIVARIATE, A×C (Hours)							TIME MEANS C
	3	4.26	4.15	3.96	3.86	3.42	3.93
	6	4.19	4.08	3.88	3.61	3.34	3.82
	9	4.27	4.10	3.85	3.59	3.37	3.84
	12	4.17	4.16	3.71	3.59	3.33	3.79
	15	4.12	4.14	3.78	3.52	3.37	3.78
BIVARIATE, A×B (°C)							TEMP. MEANS B
	50°	4.23	4.15	4.09	3.91	3.28	3.93
	60°	4.20	4.13	3.76	3.52	3.46	3.81
	70°	4.18	4.09	3.67	3.47	3.35	3.75
GROUP MEANS							OVERALL MEAN
A		4.20	4.12	3.84	3.64	3.36	3.83

accompanied by a decrease in absorption capacity which amounted to 0.12 gram of water per gram of rice, whereas the 10-degree rise from 60° to 70°C corresponded to a decrease of only 0.06 gram of water per gram of rice. Computed as percentages, these values indicate that the water absorption capacity of milled rice was reduced 4.1% and 2.1%, respectively, during soaking, depending on whether the temperature was increased from 50° to 60°C or from 60° to 70°C.

Increasing the elapsed time during which the rough rice was soaked in hot water very significantly ($p < 0.01$) reduced the water uptake ratio of milled rice. Soaking periods of 3, 6, 9, 12, and 15 hours were associated with water uptake ratios of 3.93, 3.82, 3.84, 3.79, and 3.78, respectively. The difference between the largest and smallest ratios, which were associated with 3 and 15 hours of soaking, respectively, represented a reduction in absorption capacity which was equivalent to 0.14 gram of water per gram of raw rice; this corresponded to a decrease of 4.8%.

Two of the bivariate interactions, A × C and B × C, were not significant ($p > 0.05$), whereas the A × B interaction was highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples was associated with the largest ratios, which ranged from 4.18 to 4.23. Associated with unsteamed rice samples that had been soaked at 50°, 60°, and 70°C, were mean ratios of 4.15, 4.13, and 4.09, respectively. Among the three steamed groups the ratios ranged from 4.09 to 3.28; the larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had also been soaked at 50°C but were steamed at 120°C. This indicates that, with respect to mean water uptake ratios, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, the group of untreated rough rice samples was associated with water uptake ratios that ranged from 4.12 to 4.27. The mean values for unsteamed samples that had been soaked in hot water for 3, 6, 9, 12, and 15 hours were 4.15, 4.08, 4.10, 4.16, and 4.14, respectively. Among the three steamed groups the mean ratios ranged from 3.33 to 3.96; the smaller value was associated with samples that had been soaked for 12 hours and then steamed at 120°C, whereas the larger value was associated with a 3-hour period of soaking followed by steaming at 100°C. Statistically, the A × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios, the relationship between groups of samples × elapsed time during soaking was consistently maintained for all batches of rice.

In the B × C interaction, increasing either the temperature of the water in which the rough rice was soaked, or the length of time during which it was soaked, reduced the water uptake ratio of cooked milled rice. The largest value, 4.06, was associated with samples that had been soaked in water at 50°C for 3 hours, whereas the smallest value, 3.68, was associated with samples that had been soaked at 70°C for 12 hours. Statistically, the B × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios, the relationship between water temperature during soaking × elapsed time during soaking was consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with water uptake ratios that ranged from 4.05 to 4.36, with the mean being 4.20. For the samples that had been soaked in hot water but not steamed, the ratios ranged from 4.01 to 4.26; the smaller value was associated with samples that had been soaked for 6 hours at 70°C, whereas the larger value was associated with 3 hours of soaking at 50°C. For the 45 steamed samples, the ratios ranged from 3.21 to 4.22; the smaller value was associated with samples that had been soaked for 12 hours at 50°C and then steamed at 120°C, whereas the larger value was associated with 3 hours of soaking at 50°C followed by steam treatment at 110°C. In general, increasing the temperature of the steam treatment, or increasing the temperature of the water in which the samples were soaked, or increasing the elapsed time during which the samples were soaked, tended to reduce the mean water uptake ratios. The trivariate interaction was not significant ($p > 0.05$). This indicates that, with respect to mean water uptake ratios of milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistently maintained for all batches of rice.

Volume of Cooked Milled Rice

The volume measurements were recorded as milliliters of cooked rice that were obtained from 5 grams of uncooked milled rice which had been cooked under standardized conditions.

The mean values for volumes of cooked rice for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, $A \times B$, $A \times C$, and $B \times C$; and the trivariate interaction, $A \times B \times C$, along with the overall mean are given in Table 8.

Among the 150 individual samples of cooked milled rice, the volumes ranged from 14.00 ml to 21.23 ml, with the overall mean being 17.62 ml. For Replicate I the mean value was 17.52 ml, and for Replicate II it was 17.72 ml. Although small, the difference between these two means was significant ($p < 0.05$).

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the volumes of cooked milled rice. The mean values associated with the five treatments were: untreated rice, 19.95 ml; rice that had been soaked in hot water but not steamed, 18.89 ml; and for the samples steamed at 100°, 110°, and 120°C, the volumes were 17.44, 16.50, and 15.32 ml, respectively. These values indicate that the soaking operation reduced the mean volume of cooked rice 1.06 ml, or 5.3%, which is in comparable agreement with the 4.3% reduction in water absorption capacity attributed in the preceding section to the soaking operation. The steaming process was associated with a further reduction in volume of cooked rice. The greatest reduction, corresponding to a decrease of 23.2%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a very significant effect ($p < 0.01$) on the mean

TABLE 8.—MEANS OF VOLUME OF COOKED MILLED RICE
(Milliliters of cooked rice from five grams of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	19.64	20.16	18.88	18.75	15.52	18.59
	6	19.26	18.76	18.58	17.90	15.53	18.01
	9	20.44	18.76	18.10	17.46	15.40	18.03
	12	20.00	18.30	18.18	17.05	15.38	17.78
	15	20.25	18.52	18.00	17.20	15.00	17.80
60°	3	19.74	18.51	17.88	17.75	15.76	17.93
	6	19.92	18.18	17.30	17.00	15.36	17.55
	9	20.02	18.75	16.95	15.62	15.81	17.43
	12	19.66	19.25	16.75	15.76	15.60	17.40
	15	20.05	18.75	16.38	15.52	15.00	17.14
70°	3	20.00	18.88	17.52	16.38	15.30	17.62
	6	19.86	19.20	17.82	15.62	14.75	17.45
	9	20.54	18.75	16.75	14.88	15.25	17.23
	12	20.25	19.25	16.50	15.50	15.15	17.33
	15	19.55	19.37	16.00	15.10	15.05	17.02
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	19.79	19.18	18.09	17.62	15.53	18.04
	6	19.68	18.71	17.90	16.84	15.22	17.67
	9	20.34	18.75	17.27	15.99	15.49	17.57
	12	19.97	18.94	17.14	16.10	15.38	17.50
	15	19.95	18.88	16.79	15.94	15.02	17.32
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	19.92	18.90	18.34	17.67	15.37	18.04
	60°	19.88	18.69	17.05	16.33	15.51	17.49
	70°	20.04	19.09	16.92	15.50	15.10	17.33
GROUP MEANS A		19.95	18.89	17.44	16.50	15.32	OVERALL MEAN 17.62

volumes of cooked milled rice. Mean volumes of 18.04, 17.49, and 17.33 ml were associated with soaking temperatures of 50°, 60°, and 70°C, respectively. These values indicate that increasing the temperature of the water in which the rough rice samples were soaked reduced the volume of the cooked rice. This, in turn, suggests that the higher the temperature of the water during the soaking operation, the longer will be the cooking time required to produce cooked rice of soft consistency.

Increasing the length of time that the rough rice samples were soaked in hot water prior to milling very significantly ($p < 0.01$) reduced the mean values for volume of cooked milled rice. The five periods of time during which the rough rice was soaked, namely, 3, 6, 9, 12, and 15 hours, were associated with mean volumes of 18.04, 17.67, 17.57, 17.50, and 17.32 ml, respectively.

Two of the bivariate interactions, A × B and A × C, were highly significant ($p < 0.01$), whereas the B × C interaction was not significant ($p > 0.05$).

In the A × B interaction, the group of untreated rough rice samples was associated with the largest volumes of cooked rice, which ranged from 19.92 ml to 20.02 ml. Associated with the unsteamed rice samples that had been soaked at 50°, 60°, and 70°C were mean volumes of 18.90, 18.69, and 19.09 ml, respectively. Among the three steamed groups the volumes ranged from 18.34 ml to 15.10 ml; the larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had been soaked at 70°C and steamed at 120°C. Statistically, the A × B interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, the group of untreated rough rice samples was associated with the largest volumes of cooked rice, which ranged from 19.68 ml to 20.34 ml. The mean values for the unsteamed samples that had been soaked in hot water ranged from 18.71 ml, which was associated with a 6-hour period of soaking, to 19.18 ml, which was associated with 3 hours of soaking. Among the three steamed groups of samples the mean values ranged from 15.02 ml to 18.09 ml. The larger value was associated with samples that had been soaked for 3 hours and then steamed at 100°C, whereas the smaller value was associated with 15 hours of soaking followed by steam treatment of 120°C. In general, increasing either the temperature of the steam or the length of time the samples were soaked in hot water tended to reduce the mean volume of the cooked rice. Statistically, the A × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between groups of samples × elapsed time during soaking was not consistently maintained for all batches of rice.

In the B × C interaction, increasing the temperature of the water in which the samples were soaked, or increasing the length of time during which the samples were soaked, tended to reduce the volume of cooked rice. The mean volumes ranged from 17.02 ml, which was associated with samples that had been soaked 15 hours at 70°C, to 18.59 ml, which was associated with 3 hours of soaking at 50°C. Statistically, the B × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean volumes of cooked milled rice, the relationship between water temperature during soaking × elapsed time during soaking was consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean volumes of cooked rice that ranged from 19.26 ml to 20.54 ml, with the average for the group being 19.95 ml. The mean values for the unsteamed samples that had been soaked in hot water ranged from 18.18 ml to 20.16 ml; the larger value was associated with samples that had been soaked for 3 hours at 50°C, whereas the smaller value was associated with 6 hours of soaking at 60°C. For the 45 steamed samples the mean volumes of cooked rice ranged from 14.75 ml to 18.88 ml; the larger value was associated with samples of rough rice that had been soaked in water at 50°C for 3 hours and then steamed at 100°C, whereas the smaller value was associated with 6 hours of soaking at 70°C followed by steam treatment at 120°C. The effects of increasing the water temperature during soaking and increasing the elapsed time during soaking on reducing the mean volumes of cooked rice were less pronounced for the group of samples that had been steamed at 120°C than they were for the four other groups of samples. Statistically, the trivariate interaction was not significant ($p > 0.05$). This indicates that, with respect to mean volumes of cooked milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were consistently maintained for all batches of rice.

Total Solids in the Residual Cooking Liquid

The amount of total solids that were leached from each sample of milled rice into the water during the cooking operation was determined gravimetrically and expressed as milligrams of TSRCL (total solids in the residual cooking liquid) per gram of uncooked milled rice.

The mean amounts for TSRCL for: A, group treatment that included three levels of steam temperature; B, water temperature during soaking; C, elapsed time during soaking; the three bivariate interactions, A × B, A × C, and B × C; and the trivariate interaction, A × B × C, along with the overall mean are given in Table 9.

Among the 150 individual measurements, the amounts of TSRCL ranged from 21.60 mg/g to 59.00 mg/g, with the overall mean being 40.08 mg/g. For Replicate I the mean value was 39.83 mg/g, and for Replicate II it was 41.74 mg/g. The difference between these two means was highly significant ($p < 0.01$).

The processing treatments to which the five groups of rough rice were subjected very significantly affected ($p < 0.01$) the mean amounts of TSRCL. The mean values associated with the five treatments were: untreated, 48.44 mg/g; soaked but not steamed, 46.33 mg/g; and for the samples steamed at 100°, 110°, and 120°C, the amounts were 40.30, 36.04, and 32.83 mg/g, respectively. These values indicate that the soaking operation reduced the mean amount of TSRCL to the extent of 2.11 mg/g, or 4.4%. Increasing the temperature of the steaming process further reduced the mean values for TSRCL. The greatest reduction,

TABLE 9.—MEANS FOR RESIDUAL SOLIDS IN COOKING WATER OF MILLED RICE (Milligrams of residual solids per gram of uncooked rice)

TRIVARIATE INTERACTION, A×B×C							BIVARIATE, B×C Temp.×Time)
Soaking		Group Treatment					
Temp. (°C)	Time (Hours)	Raw	Soaked	100°	110°	120°	
50°	3	46.10	49.05	48.05	35.95	34.05	42.64
	6	44.50	49.55	49.00	38.35	38.85	43.45
	9	48.90	49.30	52.30	40.70	37.60	45.76
	12	53.65	55.45	39.80	40.65	30.70	44.05
	15	47.40	46.90	38.70	36.30	32.80	40.42
60°	3	48.50	47.20	40.35	35.30	32.40	40.75
	6	45.20	44.45	37.50	34.60	36.05	39.56
	9	50.60	37.20	37.35	30.85	36.00	38.40
	12	49.25	46.25	36.85	33.85	36.20	40.48
	15	45.70	44.75	38.05	39.35	30.65	39.70
70°	3	47.50	42.95	40.15	37.90	32.25	40.15
	6	53.70	46.40	45.40	39.55	31.05	43.22
	9	51.25	43.70	35.30	34.45	32.15	39.37
	12	44.55	44.30	34.15	32.95	26.80	36.55
	15	49.80	47.45	31.50	29.90	27.95	37.32
BIVARIATE, A×C	(Hours)						TIME MEANS C
	3	47.37	46.40	42.85	36.38	32.90	41.18
	6	47.80	46.80	43.97	37.50	34.32	42.08
	9	50.25	43.40	41.65	35.33	35.25	41.18
	12	49.15	48.67	36.93	35.82	31.23	40.36
	15	47.63	46.37	36.08	35.18	30.47	39.15
BIVARIATE, A×B	(°C)						TEMP. MEANS B
	50°	48.11	50.05	45.57	38.39	34.20	43.26
	60°	47.85	43.97	38.02	34.79	34.26	39.78
	70°	49.36	44.96	37.30	34.95	30.04	39.32
GROUP MEANS A		48.44	46.33	40.30	36.04	32.83	OVERALL MEAN 40.08

corresponding to a decrease of 29.2%, occurred when the steam temperature was 120°C.

The temperature of the hot water in which the rough rice samples were soaked had a significant effect ($p < 0.05$) on the mean amounts of TSRCL. Associated with soaking temperatures of 50°, 60°, and 70°C, were mean values of 43.26, 39.78, and 39.32 mg/g, respectively. These values indicate that increasing the temperature of the water in which the rough rice samples were soaked reduced the amount of TSRCL.

The length of time that the rough rice samples were soaked in hot water did not significantly affect ($p > 0.05$) the amounts of TSRCL.

For the different periods of soaking time, namely, 3, 6, 9, 12, and 15 hours, the associated mean amounts of TSRCL were 41.18, 42.08, 41.18, 40.36, and 39.15 mg/g, respectively.

No two of the three bivariate interactions had the same degree of statistical significance. The A × B interaction was significant ($p < 0.05$); A × C was not significant ($p > 0.05$); and B × C was highly significant ($p < 0.01$).

In the A × B interaction, the group of untreated rough rice samples was associated with the largest amounts of TSRCL, which ranged from 47.85 mg/g to 49.36 mg/g. Associated with the unsteamed rice samples that had been soaked in hot water at 50°, 60°, and 70°C were mean amounts of 50.05, 43.97, and 44.96 mg/g. Among the three steamed groups the amounts ranged from 30.04 mg/g to 45.57 mg/g. The larger value was associated with 50°C as the soaking temperature and 100°C as the steaming temperature, whereas the smaller value was associated with samples that had been soaked at 70°C and steamed at 120°C. Statistically, the A × B interaction was significant ($p < 0.05$). This indicates that, with respect to mean amounts of TSRCL, the relationship between groups of samples × water temperature during soaking was not consistently maintained for all batches of rice.

In the A × C interaction, the group of untreated rough rice samples was associated with the largest amounts of TSRCL, which ranged from 47.37 mg/g to 50.25 mg/g. The mean amounts for the unsteamed samples that had been soaked in hot water ranged from 43.40 mg/g to 48.67 mg/g; the smaller amount was associated with a 9-hour period of soaking, whereas the larger amount was associated with 12 hours of soaking. Among the three steamed groups the mean amounts ranged from 30.47 mg/g to 43.97 mg/g. The larger amount was associated with samples that had been soaked for 6 hours and then steamed at 100°C, whereas the smaller amount was associated with samples that had been soaked for 15 hours followed by steam treatment at 120°C. In general, increasing either the temperature of the steam or the length of time the samples were soaked in hot water tended to reduce the mean amount of TSRCL. Statistically, the A × C interaction was not significant ($p > 0.05$). This indicates that, with respect to mean amounts of TSRCL, the relationship between groups of samples × elapsed time during soaking was consistently maintained for all batches of rice.

In the B × C interaction, the mean amounts of TSRCL ranged from 37.32 mg/g to 45.76 mg/g. The smaller amount was associated with samples that had been soaked 15 hours at 70°C, whereas the larger amount was associated with 9 hours of soaking at 50°C. Within each of the three temperature levels, 50°, 60°, and 70°C, the mean amounts of TSRCL associated with the five periods of elapsed time, namely, 3, 6, 9, 12, and 15 hours, fluctuated in different patterns. Statistically, the B × C interaction was highly significant ($p < 0.01$). This indicates that, with respect to mean amounts of TSRCL, the relationship between water temperature during soaking × elapsed time during soaking was not consistently maintained for all batches of rice.

In the trivariate interaction, A × B × C, the 15 untreated rough rice samples were associated with mean amounts of TSRCL that ranged from 44.50 mg/g to 53.70 mg/g, with the average for the group being 48.44 mg/g. The mean amounts for the unsteamed samples that had been soaked in hot water ranged from 37.20 mg/g to 55.45 mg/g. The smaller amount was associated with samples that had been soaked for 9 hours at 60°C, whereas the larger amount was associated with 12 hours of soaking at 50°C. For the 45 steamed samples the mean amounts ranged from 26.80 mg/g to 52.30 mg/g. The smaller amount was associated with samples of rough rice that had been soaked in water for 12 hours at 50°C and then steamed at 120°C, whereas the larger amount was associated with 9 hours of soaking at 50°C followed by steam treatment at 100°C. In general, increasing the temperature of the steam treatment reduced the mean amounts of TSRCL, whether the temperature of the water during soaking had been 50°, 60°, or 70°C, but increasing the elapsed time during soaking, while tending to reduce the mean amounts of TSRCL in many instances, was not infrequently associated with an increase in the mean amounts of TSRCL. Statistically, the trivariate interaction was significant ($p < 0.05$). This indicates that, with respect to mean amounts of total solids in the residual cooking liquid from milled rice, the relationships among groups of samples × water temperature during soaking × elapsed time during soaking were not consistently maintained for all batches of rice.

Optimum Conditions for Complete Gelatinization

In parboiled rice the presence of ungelatinized kernels lowers the quality of the milled product. The degree of gelatinization is affected by three variables in the parboiling process, namely, (1) temperature of the hot water in which the rough rice is soaked, (2) length of elapsed time during which the rough rice is soaked, and (3) temperature of the steam treatment.

The presence of "white belly," which is apparent when rice kernels are examined under a strong fluorescent light, is an indication that the rough rice had been insufficiently subjected to the combined effects of moisture and heat to produce complete gelatinization of the starch granules in rice kernels.

Earlier reports by Bhattacharya et al. (*7*) and Mecham et al. (*41*) are in accord with the observation here reported that increasing the temperature of the water in which the rough rice was soaked reduced the elapsed time necessary to effect complete gelatinization of the starch in the kernels.

The results of examining the kernels for the presence of "white belly" indicated that, for rough rice that had been soaked in water at 50°C, increasing the steam temperature from 100°C to 110°C had little or no effect on the optimal number of hours, 9 to 12, of soaking that was associated with complete gelatinization of starch in the kernels, whereas for rough rice soaked in water at 60°C and steamed at either 100° or 110°C, the optimal number of hours of soaking was 6 to 9, which was reduced to 3 to 6 hours by increasing the steam temperature to 120°C.

These relationships are indicated in the outline below:

OPTIMAL SOAKING PERIOD (HOURS)

SOAKING WATER TEMP. (°C)	STEAM TEMPERATURES (°C) 100°	110°	120°
50°	9-12	9-12	6-9
60°	6-9	6-9	3-6
70°	3-6	3-6	<3

SUMMARY AND CONCLUSIONS

Newly harvested, long-grain rough rice of the Dawn variety was obtained from the Rice Experiment Station, Crowley, Louisiana. Samples of this grain were parboiled under controlled conditions. The effects of four variables, namely,

(a) two replicate experiments,
(b) five group treatments that involved untreated rice, rice that had been soaked in hot water but not steamed, and rice that had been soaked in hot water and then treated for 10 minutes with steam at 100°C, at 110°C, and at 120°C,
(c) three levels of temperature, 50°, 60°, and 70°C, of the water in which the rough rice was soaked, and
(d) five periods of elapsed time, 3, 6, 9, 12, and 15 hours, during which the rough rice was soaked in water,

on eight selected qualities and characteristics of milled rice gave sets of laboratory data pertaining to: total yield of milled rice, percent of head rice in the milled product, color of milled rice, protein content of brown rice, protein content of milled rice, water uptake ratio of milled rice, volume of cooked milled rice, and residual solids in cooking water.

A total of 150 300-gram batches of rough rice were prepared. The separate batches were stored in closed polyethylene bags at 40°F until they were used.

After the samples had been soaked and steamed under the appropriate conditions, they were dried at room temperature until the moisture content was 12% as measured by means of a Motomco electric moisture tester. They were stored in new polyethylene bags at room temperature until they were milled.

Exactly 150 grams of rough rice from each sample was taken and shelled in a McGill sheller. The samples of brown rice thus obtained were kept in polyethylene bags that were stored at 40°F until they were milled in a Satake Testing Pearler, Model OM–2B. The milled rice was weighed and the total yield of milled product was computed. The samples of milled rice were individually placed in separate polyethylene bags that were stored at 40°F.

The milled rice samples were assayed for head rice by means of a Grain Sizing Device. Final separation of the broken kernels from the head rice, or unbroken kernels, was made manually, grain by grain. The samples of head rice were placed in polyethylene bags and stored at 40°F until they were used in the color, protein, and cooking tests.

The color of the milled rice was measured by means of a Gardner Digital Color and Color Difference Meter, Model X–10, with L, a, and b scales. Only whole kernels were used in the color measurements. The sample was read against a reference White Reflectance Standard No. 1093 which was supplied by the manufacturer.

The protein content was computed from the nitrogen values that were obtained by analyzing aliquots of the brown and milled rice samples by the Kjeldahl method.

The cooking test was carried out in a glass tube containing 50 milliliters of distilled water and 5 grams of rice; the tube and contents were immersed in boiling water for 20 minutes. The gruel was strained through a sieve, and after removing excess moisture the cooked rice was weighed to obtain the water uptake ratio. The volume of the cooked rice was determined by the water displacement method. The gruel was evaporated to dryness in a tared beaker; the content of residual solids was determined by gravimetric methods.

Each of the eight variables measured was evaluated according to a 5 × 3 × 5 factorial arrangement of treatments in a randomized block design with 2 replicates (A × B × C × R, where A represents group treatment that included 3 levels of steam temperature; B, soaking temperature; C, elapsed time during soaking; and R, replicates). The data for each variable were subjected to a standard analysis of variance for a mixed model in which A was regarded as a fixed effect and B and C were random effects. The major findings of these analyses are outlined below.

Total Yields of Milled Rice

The results of the analysis of variance indicated the following regarding total yields of milled rice:

(1) There was a significant difference between the two replicate means, which were 68.97% and 69.40%. In the experiments the samples in the two replicates were milled about a week apart. The higher yield is probably associated with a degree of milling that was slightly less than that associated with the smaller yield.

(2) The temperature of the water during soaking had a significant effect. Total yields of 69.02, 69.09, and 69.45% were associated respectively with water temperatures of 50°, 60°, and 70°C. Increasing temperature of the soaking water gave small increases in total yields.

(3) The length of time during which the rough rice was soaked in hot water had no significant effect; however, there was a tendency for samples that had been soaked 6 hours or longer to give slightly higher total yields than samples that had been soaked for only 3 hours.

(4) Steaming the rough rice after soaking had a significant effect, but the soaking operation alone had no significant effect. Total yields of 65.71% and 65.64% were associated respectively with untreated rice and rice that had been soaked but not steamed; total yields of 71.55, 71.49, and 71.53% were associated respectively with steam temperatures of 100°, 110°, and 120°C. The steaming operation itself increased the total yield about 6%, but increasing the temperature of the steam had no effect.

None of the interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature were significant. The effects of the trivariate interaction, soaking temperature × soaking time × steam temperature, were significant.

Yields of Head Rice

The results of the analysis of variance indicated the following regarding yields of head rice:

(1) There was a significant difference between the two replicate means, which were 80.91% and 82.48%. This finding is in agreement with a similar finding for the replicate means for total yields of milled rice.

(2) The temperature of the water during soaking did not have a significant effect. There was a tendency, however, for increased yields of head rice to be associated with elevated soaking temperatures. Head rice yields of 80.31, 80.70, and 84.08% were associated respectively with water temperatures of 50°, 60°, and 70°C.

(3) The length of time during which the rough rice was soaked in hot water had a significant effect. The yield of head rice increased until the soaking time reached 9 hours. No advantage was gained by extending the soaking time beyond 9 hours. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were head rice yields of 75.22, 81.05, 84.35, 83.86, and 84.00%, respectively.

(4) The group treatments that included three levels of steam temperature had significant effects. Head rice yields of 75.18% and 64.42% were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the yield of head rice nearly 11%. The steaming operation greatly increased the yield of head rice to 87.14, 90.31, and 91.42%,

respectively, for steam temperatures of 100°, 110°, and 120°C. The beneficial effect of the steaming operation was attributed to the gelatinization and hardening of the kernels under the moist influence of elevated steam temperatures.

The interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature were highly significant, and the trivariate interaction, soaking temperature × soaking time × steam temperature, was significant.

Color of Milled Rice

The results of the analysis of variance indicated the following regarding the color values of milled rice:

(1) Replication had no effect on the mean color values, which were almost identical for the two replicates, 31.71 and 31.72.

(2) The temperature of the water during soaking had a highly significant effect. Color values of 29.62, 31.87, and 33.65 were associated respectively with water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the soaking water caused the color of the milled product to become darker.

(3) The length of time during which the rough rice was soaked in hot water had a highly significant effect. The color of the milled product darkened by stages until the soaking time reached 12 hours; extending the soaking time to 15 hours did not affect the color. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were color values of 29.56, 31.10, 31.74, 33.07, and 33.09, respectively.

(4) The group treatments that included three levels of steam temperature had significant effects. Color values of 21.37 and 25.05 were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to darken the milled product, and the steaming operation darkened the color still further as indicated by the three color values 33.82, 37.35, and 40.97 that were associated respectively with steam temperatures of 100°, 110°, and 120°C.

The interactions of the effects of soaking temperature × soaking time, soaking temperature × steam temperature, and soaking time × steam temperature, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were highly significant.

Protein Content of Brown Rice

The results of the analysis of variance indicated that replication had no effect on the mean values of protein content, which, for the two replicates of 75 samples each, were 8.24% and 8.22%. Likewise, the temperature of the soaking wate., the length of soaking time, and the steam temperature had no significant effects on the protein content of brown rice.

Protein Content of Milled Rice

The results of the analysis of variance indicated that replication had no effect on the mean values of protein content, which, for the two replicates of 75 samples each, were 7.11% and 7.13%. Similarly, the temperature of the soaking water, the length of soaking time, and the steam temperature had no significant effects on the protein content of milled rice.

Water Uptake Ratio of Milled Rice

The results of the analysis of variance indicated the following regarding water uptake ratios of milled rice:

(1) There was a significant difference between the two replicate means, which were 3.81 and 3.86. The difference between these two values represented 0.05 gram of water and corresponded to a difference of 1.8% in capacity to absorb water. This finding of a significant difference between replicate mean values for water uptake ratio is in agreement with similar findings for replicate means of total yields of milled rice and yields of head rice.

(2) The temperature of the water during soaking was highly significant. Water uptake ratios of 3.93, 3.81, and 3.75 were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the water in which the rough rice was soaked reduced the water uptake ratio of the milled product.

(3) The length of time during which the rough rice was soaked in hot water was highly significant. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were water uptake ratios of 3.93, 3.82, 3.84, 3.79, and 3.78, respectively. The maximum reduction in values occurred after 15 hours of soaking, and it was equivalent to 0.15 gram of water; this represented a 5.1% decrease in the capacity of the milled product to absorb water.

(4) The group treatments that included three levels of steam temperature were highly significant. Water uptake ratios of 4.20 and 4.12 were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the water uptake ratio. The steaming operation further reduced the water uptake ratios to 3.84, 3.64, and 3.36, respectively, for steam temperatures of 100°, 110°, and 120°C. The reduced values indicate that soaking the rough rice in hot water reduced the water absorption capacity of the milled product 4.3% relative to the capacity of untreated rice and that, furthermore, soaking in hot water followed by steaming at 120°C effected a reduction of 27.6%.

The interactions of the effects of soaking temperature × soaking time, soaking time × steam temperature, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were not significant. The interaction of the effects of soaking temperature × steam temperature was highly significant.

Volume of Cooked Milled Rice

The results of the analysis of variance indicated the following regarding the volumes of cooked milled rice:

(1) There was a significant difference between the two replicate means, which were 17.52 ml and 17.72 ml. This finding is in agreement with similar findings for water uptake ratios, yields of head rice, and total yields of milled rice.

(2) The temperature of the water in which the rough rice was soaked was highly significant. Volumes of 18.04, 17.49, and 17.33 ml were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature of the water in which the rough rice was soaked reduced the volume of the cooked milled product. This finding suggests that the higher the temperature of the water during soaking, the longer will be the cooking time required to produce cooked rice of soft consistency.

(3) The length of time during which the rough rice was soaked in hot water was highly significant. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were cooked milled rice volumes of 18.04, 17.67, 17.57, 17.50, and 17.32 ml, respectively. Increasing the length of the soaking time reduced the volume of the cooked milled rice.

(4) The group treatments that included three levels of steam temperatures were highly significant. Cooked milled rice volumes of 19.95 ml and 18.89 ml were respectively associated with untreated rice and rice that had been soaked but not steamed. The effect of the soaking operation was to reduce the volume of the cooked milled rice. The steaming operation further reduced the volumes to 17.44, 16.50, and 15.32 ml, respectively, for steam temperatures of 100°, 110°, and 120°C.

The interactions of the effects of soaking temperature × soaking time, and the trivariate interaction, soaking temperature × soaking time × steam temperature, were not significant. The interactions of the effects of soaking temperature × steam temperature, and soaking time × steam temperature, were highly significant.

Residual Solids in Cooking Water

The results of the analysis of variance indicated the following regarding the residual solids in cooking water:

(1) There was a highly significant difference between the two replicate means, which were 39.83 and 41.74 milligrams of residual solids per gram of uncooked milled rice. This finding is in agreement with similar findings for replicates for volumes of cooked milled rice, water uptake ratios, yields of head rice, and total yields of milled rice.

(2) The temperature of the water in which the rough rice was soaked was significant. Residual solids in the cooking water amounting to 43.26, 39.78, and 39.32 mg/g were associated respectively with soaking water temperatures of 50°, 60°, and 70°C. Increasing the temperature

of the water in which the rough rice was soaked reduced the amount of residual solids in the cooking water.

(3) The length of time that the rough rice was soaked in hot water was not significant. There was a tendency, however, for smaller amounts of solids in the cooking water to be associated with longer periods of soaking time. Associated with the five periods of soaking time, 3, 6, 9, 12, and 15 hours, were respectively, in milligrams of solids per gram of uncooked milled rice, 41.18, 42.08, 41.18, 40.36, and 39.15 mg/g.

(4) The group treatments that included three levels of steam temperature were highly significant. The residual solids in the cooking water amounted to 48.44 mg/g and 46.33 mg/g, respectively, for untreated rice and rice that had been soaked but not steamed. The soaking operation slightly reduced the amount of solids in the cooking water. The steaming operation further reduced the amounts to 40.30, 36.04, and 32.83 mg/g, respectively, for steam temperatures of 100°, 110°, and 120°C.

The interaction of the effects of soaking time × steam temperature was not significant. The interaction of the effects of soaking temperature × soaking time was highly significant, whereas that of soaking temperature × steam temperature was significant, as was also the trivariate interaction, soaking temperature × soaking time × steam temperature.

Optimal Length of Soaking Period

The optimal length of the soaking period necessary to bring about complete gelatinization of starch in rice kernels ranged from 9 to 12 hours to less than 3 hours, depending upon the soaking temperature and the steam temperature. The longer periods were associated with rough rice that had been soaked at 50°C and then steamed at either 100° or 110°C, whereas the shortest period of optimal soaking time was associated with samples of rough rice that had been soaked at 70°C followed by treatment with steam at 120°C.

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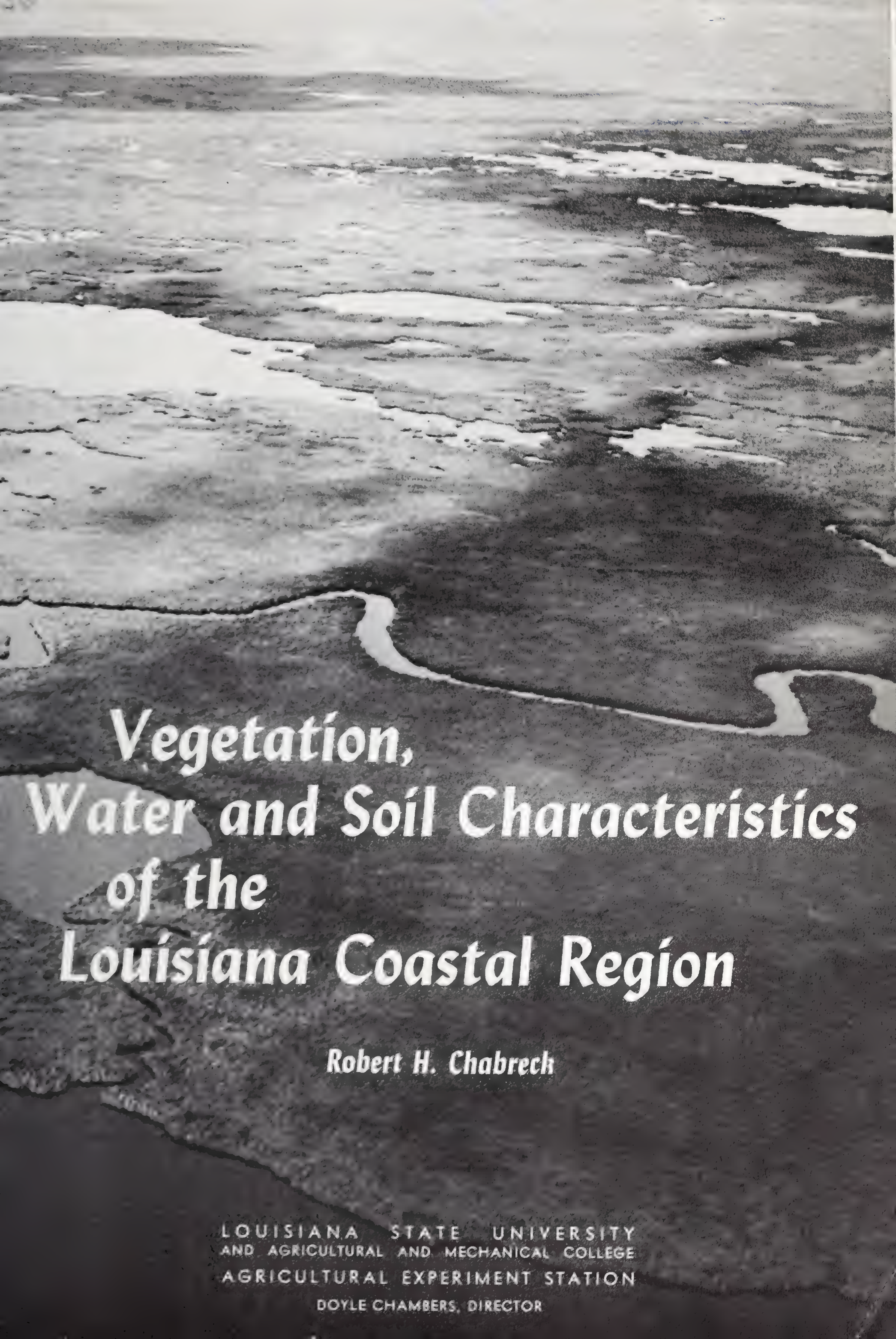

Vegetation, Water and Soil Characteristics of the Louisiana Coastal Region

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ABSTRACT

The vegetation, soils, and waters were sampled in the Louisiana Coastal Marshes in August 1968. The coastal region was subdivided into geographical units for descriptive purposes and the vegetation, water, and soil characteristics of each area determined. The surface features of each subdivision including marshes, water bodies, swamp, and dry land were measured and the area of each feature presented.

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Vegetation, Water and Soil Characteristics Of the Louisiana Coastal Region

ROBERT H. CHABRECK[1]

INTRODUCTION

The Louisiana Coastal Region encompasses an area of almost 8 million acres. This area originated mostly from alluvial deposits of the Mississippi River and its distributaries. Over the centuries these deposits accumulated to form a broad, flat plain.

About one-half of the coastal region is made up of water bodies, including ponds, lakes, bays, sounds, bayous, rivers, canals, and ditches. Natural marshes make up about one-third of the coastal region and the remainder consists of dry land such as beaches, cheniers, spoil deposits, bayou and lake banks, and dewatered marshes or pump-outs.

The marshes and adjacent water bodies encompass the full coastline of the state and vary in width from 15 to 50 miles. Since these marshes extend inland from the Gulf of Mexico for such great distances, widely varying environmental conditions occur.

Soil and water conditions within the coastal zone regulate plant growth, and different environmental factors produce different plant communities (Penfound and Hathaway, 1938). Generally, the set of conditions in a particular area is favorable for the growth of a number of species; and, so long as a specific environment prevails, the species will occupy the site. However, a change in conditions will usually result in a change in plant species (O'Neil, 1949). Chamberlain (1957) reported that natural vegetational changes appeared to be an adjustment of the vegetation to development of marsh soil and variation in salinity and water levels.

The coastal marshes and estuaries are tremendous producers of fur-bearing animals and other wildlife resources (O'Neil, 1949; St. Amant, 1959). Cattle grazing is an important land-use practice, and the water bodies associated with coastal marshes are well known for their high production of marine organisms (Gunter, 1967; Chabreck, 1968).

The high animal productivity of the Louisiana Coastal Region is directly related to the abundance and diversity of plant growth. Photosynthetic plants are the foundation upon which the ultimate yield of these resources rests (Palmisano, 1970), and soil and water conditions which enhance plant growth are vital to the continued productivity of the area.

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A survey was made of the Louisiana Coastal Region in August 1968, and this publication reports the findings of that survey. The coastal region is subdivided into various physiographic units for descriptive purposes, and the vegetation, water, and soil characteristics of each subdivision are summarized. This report gives special emphasis to the coastal marshes and the water bodies associated with the marshes. No attempt is made to correlate vegetation, water, or soil variables.

DESCRIPTION OF THE AREA

Topography

The entire Louisiana Coastal Region was included in this study, extending from Texas to Mississippi and from the Gulf of Mexico inland to the northern boundary of the marshes. The northern edge of the marsh extends slightly beyond the Intracoastal Waterway, with a few exceptions.

The Louisiana Coastal Marshes are a part of the coastal region and are bounded on three sides by bodies of water, and in many areas lakes, bayous, and canals are so abundant that the marsh appears not as a land mass at all, but rather a vast region of small islands. In other regions the opposite exists, and marsh vegetation grows in vast unbroken stands covering as much as 1 square mile.

The coastal marshes, in general, are without distinct relief features. The marsh in most areas is only slightly above mean Gulf level. Most noticeable are the low natural levee ridges along tidal channels and larger streams flowing into or through the marsh (Lytle and Driskell, 1954). Also, Brown (1936) reported a striking contrast between the vegetation on Indian mounds and middens and that of the surrounding marshes. Artificial levees and spoil deposits in recent years have greatly altered the topographic features in practically all areas of the coastal marshes.

Coastal Origin

The Louisiana Coastal Marshes are a product of the Mississippi River. During the Recent Period, seven Mississippi River delta systems have developed because of diversions in the river channel. The large number of deltas has caused considerable variation in the physiography of the area. During the coastal development process, Prairie Formation deposits of Pleistocene Age were overlain with a wedge of recent sediment primarily from the Mississippi River (Kniffen, 1968).

The coastal region has been divided into two segments on a basis of origin and physiography. The area east of Vermilion Bay and occupying two-thirds of the coastal region has been designated as the Deltaic Plain. The Deltaic Plain is the site of the various delta systems. The area west of Vermilion Bay has been named the Chenier Plain and was formed from river sediment swept westward by longshore currents in the Gulf of Mexico (Coleman, 1966).

Over a period of some 8,000 years the Mississippi River has altered its course periodically, forming new deltas with each move. When viewed at the present time, older deltas show less rate of change than the younger deposits. The older deltas, having had more time for compaction, subsidence, and wave modification, show greater stability (Morgan and Larimore, 1957).

Continuous subsidence over a long period of years has modified the older deltas so that original deposits are far below sea level. Breton Sound, Chandeleur Sound, Barataria Bay, and Timbalier Bay are typical areas which were formerly marshes on the outer reaches of deltas but were lost because of subsidence. O'Neil (1949) described such water bodies as drowned marsh. Within the same delta system submergence of original deposits has also taken place further inland. However, subsidence is less noticeable here because of the extensive floating marshes which have developed (Russell, 1942).

The developmental process of the Chenier Plain was considerably different from that of the Deltaic Plain. Silt and clay sediment from the Mississippi River was carried westward by currents in the Gulf of Mexico and gradually accumulated as mud flats against the shoreline. The amount of material carried and the duration of flow determined the extent of the buildup. The mud flats soon became occupied by salt-tolerant vegetation and new marsh was thus created (Coleman, 1966).

The building process in the Chenier Plain continued until a change in the river's course resulted in a loss of sedimentary material. Once the building process ceased, the new marsh came under attack by wave action. Shoreline retreat then followed, with a corresponding formation of local beach deposits. The beach deposit remained along the point of wave attack until another change in course caused a resumption in the buildup along the shoreline. This process caused the marshes to again advance seaward, leaving the beaches stranded (Russell and Howe, 1935).

The stranded beaches, or cheniers as they are termed locally, extend in an east-west direction and have a strategic role in the drainage patterns of the Chenier Plain. In contrast, topographic features of the Deltaic Plain, such as the natural levees of past and present drainage systems, generally run in a north-south direction.

O'Neil (1949) used the term Prairie Marshes in describing the marshes of the Chenier Plain in Southwestern Louisiana and characterized the area as being poorly drained and having shallow peat soils. He classified the marshes of the Deltaic Plain as Delta Marshes and Subdelta Marshes and stated that the basic geology of the areas was similar. Noticeable differences occurred, however, in the plant communities of the two areas as a result of subsidence, peat deposits, and salinity. The marshes of the Deltaic Plain are referred to as marsh zones (Chabreck, 1970) and termed Inactive Delta Marsh Zone and Active Delta Marsh Zone (Figure 1).

The Active Delta Marsh Zone, which consists of the present Mississippi River Delta, is greatly influenced by the vast amount of fresh water supplied by the river and its distributaries. Daily tidal action in the older Inactive Delta Marsh Zone and the absence of a sizeable fresh water flow resulted in saline conditions over a large portion of the area.

Soils

The coastal marsh soils are generally classified as peats, mucks, and clays, with all occurring in various proportions. The dominant morphological characteristics are the dark brown and black colors of the peats, mucks, and organic clays, and the gray colors associated with waterlogged, reduced soil conditions (Lytle, 1968).

The soil materials are silts, silty clays, and clays of recent alluvial origin, plus marine silts and clays, overlain at various locations by peats and mucks (Lytle and Driskell, 1954). The depth of the organic soil is determined by the amount of subsidence and the vegetative history of a particular area. According to Russell (1942), the organic layer has been found at depths ranging from a few inches to 20 feet.

The organic soils are classified on a basis of the stage of decomposition. Dachnowski-Stokes (1940) classified peat as soil which has a brown or black color and contains plant parts only partially decomposed and generally with over 50 percent organic matter. Mucks are usually black or dark gray and contain organic material which is finely divided and well decomposed with none of the plant parts identifiable. The organic content of muck usually ranges from 15 to 50 percent, and soils with less than 15 percent organic matter are classified as mineral soil.

Tides

The tidal cycle in the coastal areas of Louisiana is controlled largely by tides in the Gulf of Mexico, although local conditions have some influence. As in most large bodies of water, the dynamics of tides in the Gulf of Mexico is a complicated problem. The irregular shape of its basin and connections with the Atlantic Ocean and Caribbean Sea cause co-oscillation with the tidal movements in those bodies of water (Marmer, 1954).

At any location the tides not only vary in range from day to day, but also from month to month and year to year. The changes in range and character of tides are influenced primarily by changing positions of the moon in relation to the earth and sun, with different localities responding in a different fashion. The tidal cycle follows the moon cycle with two principal types of fluctuations, the daily tide and the semidaily tide. According to Marmer (1954), the fluctuations occur at intervals with an average length of 24 hours and 50 minutes along the northern Gulf coast.

Gunter (1967) reported that at the beginning of the cycle tides are normally the daily type with one maximum and one minimum each day. The maximum fluctuation is 26 inches, which occurs only once a month. Then, every succeeding day it declines slightly until the variation is only 2 or 3 inches a day with the tide standing a little above mean low. This is further complicated by a changeover to semidaily tides during the period of small fluctuations. The semidaily tides have two high waters and two low waters in a tidal day, with an interval between highs of about 12 hours and 30 minutes (Marmer, 1954).

The periodic rise and fall of the tide is subject to the effects of changing weather conditions. Changing meteorological conditions may change the level of the water from which the tides rise and fall, altering both the time of occurrence and the levels of high and low tides. With strong southerly winds, Gulf waters will pile up along the Louisiana coast and move inland through the many bays, bayous, and canals. Periods with prolonged winds frequently result in inundation of the marshes. The depth of flooding is determined by the duration and velocity of the winds, the elevation of the marsh, and its distance from the Gulf. Extremely high tides are associated with tropical storms and hurricanes, and tide water may be pushed inland for considerable distances.

During the winter strong northerly winds have an opposite effect, and at times tides as low as 2 feet below normal are not uncommon. Marshes drained by tidal channels will be practically dry at such times. Channel size determines the rate of water exchange, and interior marshes connected to the Gulf by large channels are influenced to a greater extent by tides than marshes with small drainage systems. Gunter (1967) reported that heavy local rainfall would raise water levels in back bays and other coastal areas having slow drainage. Such rains have a slight disturbance on tide levels, but the effects are only temporary. According to Nichols (1959), periods of high water during rainy seasons in adjacent upland areas may curtail the tidal effect in the marsh streams until the freshwater level is lowered to that of the current high tide level.

A study of tide levels along the central Louisiana coast at Marsh Island by Chabreck and Hoffpauir (1962) revealed considerable monthly differences in mean tides. During the period included, 1958 and 1959, the area was not influenced by tropical storms or hurricanes; therefore, the tide levels as shown in Table 1 could be considered normal. The data were collected using continuous water level recorders and showed that tides ranged from a mean high of 1.26 feet above sea level in September to a mean low of minus 0.62 foot in December. The mean tide level over the 24-month period was 0.43 foot above sea level. Normal marsh elevations on the Chenier Plain average about 1 foot above sea level (Nichols, 1959), and because of subsidence, elevations on the Deltaic Plain average even less. Although normal high tides commonly inundate the marshes, mean marsh levels are several inches above mean tide levels, thus favoring the growth of emergent vegetation.

Table 1. Monthly tide levels along the Central Louisiana coast, 1958-59[a]

Month	Mean High Tide	Mean Low Tide	Mean Water Level	Highest Individual Tide	Lowest Individual Tide
	- - - - - - - -	- - - - - -	Feet	- - - - - -	- - - - - -
January	.39	-.35	.02	1.5	-2.0
February	.56	-.26	.15	1.6	-1.8
March	.60	-.18	.21	1.3	-1.5
April	.78	.09	.43	1.2	- .7
May	1.13	.40	.76	2.4	- .7
June	1.19	.18	.69	1.7	- .7
July	.83	-.06	.39	1.5	-1.0
August	.83	.11	.47	1.6	- .8
September	1.26	.69	.97	2.6	- .2
October	1.06	.39	.72	1.8	- .5
November	.85	.07	.46	1.5	-2.1
December	.37	-.62	-.12	1.4	-2.2
Annual	.82	.04	.43	2.6	-2.2

[a] From Chabreck and Hoffpauir, 1962.

Climate

The climate along the Louisiana coast is influenced greatly by its subtropical latitude and its proximity to the Gulf of Mexico. The marine tropical effect results from the fact that the average water temperature of the Gulf along the Louisiana shore ranges from 64° F in February to 84° F in August (Sanders, 1959). Prevailing southerly winds in summer provide moist, semitropical weather and frequently produce afternoon thundershowers. Whenever westerly or northerly winds interrupt the prevailing moist conditions during the summer, hotter and dryer weather results. During the winter the state is subjected to alternating cold continental air and warmer tropical air, causing drastic variations in climatic conditions.

The mean monthly temperature, as shown in Table 2, is lowest in January and highest in August. Mean temperatures vary only slightly going from west to east across the state. The mean temperature in the spring and summer of 1968, prior to this study, compared favorably with the 25-year average. Temperatures in February averaged about 9° F below normal; otherwise, monthly temperature averages in 1968 were within 2° of the 25-year average. According to Kniffen (1968) the growing season along the Louisiana coast, or the period between the last freeze in the spring and the first in the fall, averages 317 days.

The Louisiana coast generally has an abundance of rainfall, with annual averages ranging from 57.86 inches at Lake Charles to 66.14 inches at Morgan City (Table 2). The rainfall is fairly well distributed throughout the year, with the maximum occurring in July and the

Table 2. A comparison of the twenty-five year mean monthly temperature and precipitation with the 1968 mean monthly temperature and precipitation along the Louisiana coast

	Lake Charles		Lafayette		Morgan City		Houma		New Orleans	
Month	25 yr.	1968	25 yr.	1968	25 yr.	1968	25 yr.	1968	25 yr.	1968
	Temperature (F^o)									
Jan.	52.6	50.8	54.1	51.5	56.5	53.1	56.9	54.0	54.9	51.6
Feb.	55.9	46.6	56.5	46.7	58.6	49.5	58.6	49.8	57.4	47.2
March	60.6	58.2	61.3	57.4	63.0	58.5	62.7	59.4	61.7	55.9
April	68.0	70.5	68.0	69.6	68.9	71.4	68.8	71.6	68.3	68.1
May	74.5	74.8	74.8	74.6	75.5	75.1	74.9	75.2	74.6	74.1
June	80.7	79.8	80.8	80.1	81.1	80.9	80.1	80.7	80.5	80.4
July	82.2	81.5	82.0	80.8	82.1	81.7	81.4	80.9	81.8	82.4
Aug.	82.3	81.9	82.0	80.7	82.3	81.9	81.6	81.2	82.2	81.0
Sept.	78.6	75.6	78.1	75.9	78.9	77.3	78.2	77.3	79.5	75.4
Oct.	70.3	69.7	69.6	70.3	71.1	72.3	70.3	72.0	71.4	68.5
Nov.	59.3	56.9	59.1	56.7	60.7	58.8	60.7	59.9	60.9	55.5
Dec.	54.0	52.2	54.9	52.4	56.9	53.6	57.3	54.9	56.1	50.8
Annual	68.3	66.5	68.4	66.4	69.6	67.8	69.3	68.1	69.1	65.9

	Lake Charles		Lafayette		Morgan City		Houma		New Orleans	
Month	25 yr.	1968	25 yr.	1968	25 yr.	1968	25 yr.	1968	25 yr.	1968
	Precipitation (Inches)									
Jan.	4.82	3.89	5.47	3.53	5.00	1.42	4.18	1.60	4.68	.54
Feb.	4.53	2.68	4.23	3.43	5.06	3.59	3.85	3.67	3.97	3.02
March	4.76	2.76	4.63	3.05	5.07	2.76	5.25	2.57	5.90	3.49
April	4.27	2.39	4.69	2.56	4.52	5.66	4.61	7.27	5.40	3.59
May	4.73	3.16	5.09	6.43	4.58	3.07	4.26	2.10	5.54	4.13
June	5.08	8.90	5.11	4.65	5.29	6.43	6.09	3.97	5.63	3.69
July	6.93	7.82	7.06	3.30	8.73	6.78	8.45	5.03	5.89	4.96
Aug.	4.66	3.59	6.11	3.76	7.53	6.66	7.34	7.40	5.64	4.78
Sept.	4.53	3.11	4.10	3.90	7.14	5.77	6.31	3.39	5.06	2.44
Oct.	3.44	2.38	2.73	1.34	2.99	3.93	3.43	.63	3.18	1.40
Nov.	4.34	5.83	4.39	6.65	4.55	5.60	4.47	4.59	4.09	4.97
Dec.	5.76	4.73	5.58	3.16	5.68	5.10	5.15	8.53	4.67	6.14
Annual	57.86	51.24	59.19	45.76	66.14	56.77	63.39	50.75	59.65	43.15

Source: Sanders (1959) and U. S. Weather Bureau (1969).

minimum in October. Annual precipitation during 1968 was below the 25-year average at all stations checked; however, no outstanding drought periods were noted.

Hurricanes and tropical storms with strong cyclonic winds, high tides, and torrential rain are occasional visitors to the coastal region between June and November (Nichols, 1959). These storms generally approach Louisiana from the southeast and move inland with terrific force. Over the past 15 years five major hurricanes have struck the Louisiana coast, greatly altering conditions in the region.

METHODS AND MATERIALS

Subdivision of the Coastal Region

Subdivisions of the coast were made on a basis of hydrologic units and vegetative types. The hydrologic units provided for a grouping of areas with a common drainage system. The coastal region was subdivided into nine hydrologic units (Figure 1) and four vegetative types (Figure 2).

Hydrologic Units

Hydrologic Unit 1. Unit 1 includes the Lake Pontchartrain-Lake Borgne drainage systems and exits on the eastern side of the state. The unit extends seaward as far as Chandeleur Islands and is bound on the northeast side by the Pearl River. The southern boundary begins at Breton Island and runs northwest across Breton Sound to Mozambique Point and the mouth of Bayou Terre aux Boeufs. It then extends northwest up Bayou Terre aux Boeufs to the town of Delacroix, then north up Louisiana Highway 600 to Reggio and west along Highway 46 to Poydras and the Mississippi River. The boundary then reaches upstream along the centerline of the Mississippi River to Donaldsonville.

Hydrologic Unit 2. The northern boundary of Unit 2 follows the southern boundary of Unit 1 from Breton Island to the Mississippi River. From here Unit 2 boundary follows the Mississippi River downstream to a point about 2 miles south of Boothville. The boundary then turns northeast toward Carencro Bay, Breton Sound, and Breton Island. Unit 2 includes areas such as the Delacroix Marshes, Lake Lery, California Bay, and Breton Sound.

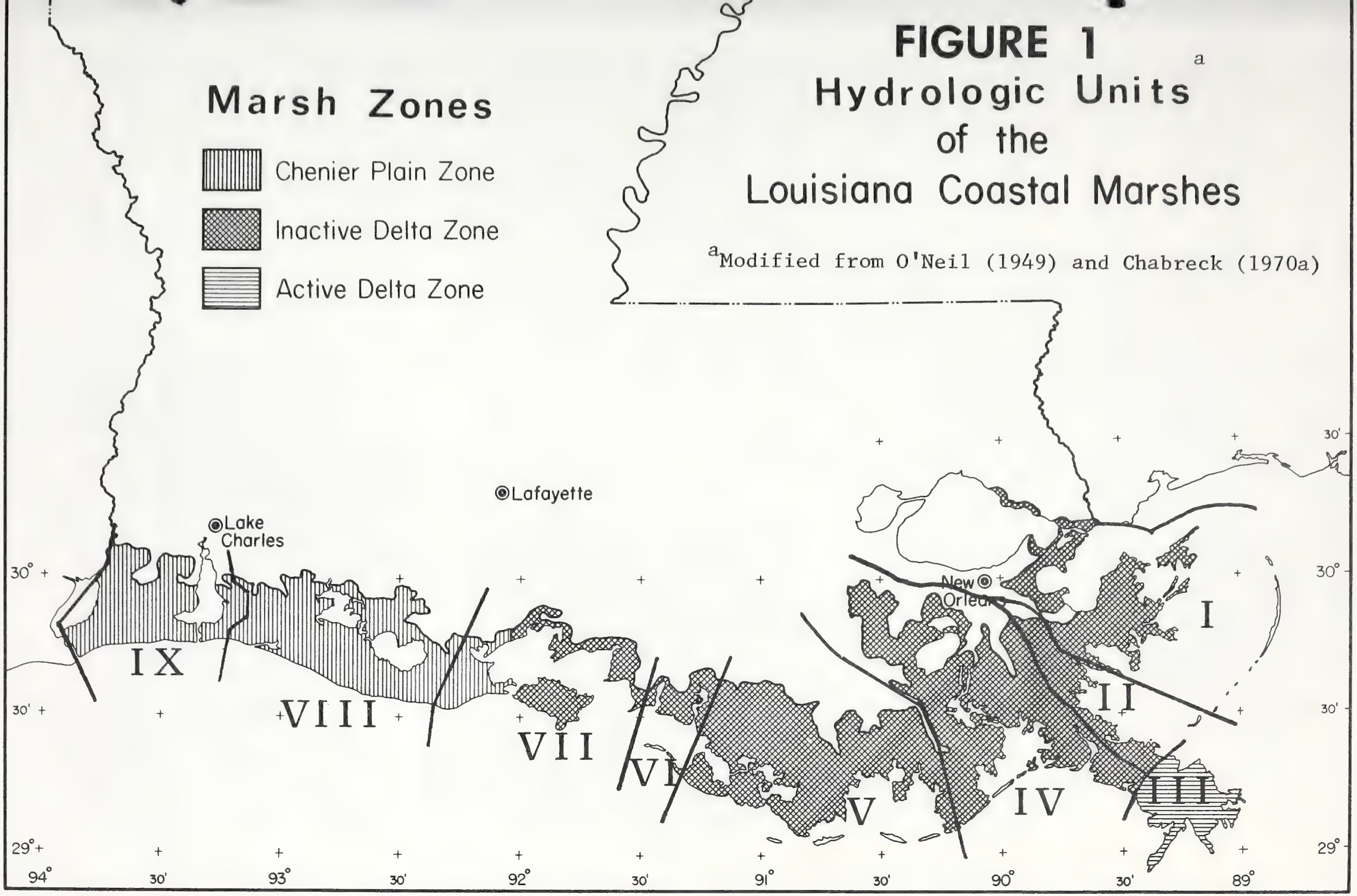
Hydrologic Unit 3. Unit 3 includes the active, bird's-foot delta of the Mississippi. It lies southeast of a line beginning at Breton Island, then extending in a southwesterly direction and crossing the Mississippi River 2 miles south of Boothville and meeting the Gulf of Mexico at Bay Coquette.

Hydrologic Unit 4. Unit 4 encompasses the Barataria Basin and runs from the Mississippi River southward to the Gulf of Mexico, having common boundaries with four other hydrologic units. It

FIGURE 1[a]

Hydrologic Units of the Louisiana Coastal Marshes

[a]Modified from O'Neil (1949) and Chabreck (1970a)



borders Unit 1 along its northern side, Unit 2 along its eastern side and Unit 3 at its southeastern corner. Bayou Lafourche forms the western boundary of Unit 4 and separates it from Unit 5.

Hydrologic Unit 5. Unit 5 has the largest marsh area and extends from Bayou Lafourche westward to the east levee of the Atchafalaya River. It includes numerous large bays such as Timbalier Bay, Terrebonne Bay, Caillou Bay, and Four League Bay, plus vast marsh areas draining into the bays.

Hydrologic Unit 6. Unit 6 is the smallest hydrologic unit and includes primarily the marsh area between the Atchafalaya River and Wax Lake Outlet.

Hydrologic Unit 7. Unit 7 includes Marsh Island, Vermilion Bay, West and East Cote Blanche Bays, and the marsh areas surrounding these bays. The eastern boundary of Unit 7 is Wax Lake Outlet. The western boundary lies along a line beginning at the Gulf of Mexico in Vermilion Parish about 5 miles west of the mouth of Freshwater Bayou Gulf Outlet. From this point the line follows a northeasterly direction to the Schooner Bayou Control Structure and the Vermilion Locks, then north from the locks to the northern boundary of the coastal marsh.

Hydrologic Unit 8. Unit 8 encompasses the Mermentau Basin, which includes the Mermentau River, Grand Lake, White Lake, and the associated marshes. Along its eastern side it shares a common boundary with Unit 7. Its western boundary begins at the Gulf of Mexico at a point 5 miles west of the Mermentau River, then runs north to Louisiana Highway 27. The boundary then follows Highway 27 east and north to the Intracoastal Waterway, then west along the Intracoastal Waterway to the Calcasieu Locks.

Hydrologic Unit 9. Unit 9 lies principally in the western half of Cameron Parish and includes the marshes drained by the Calcasieu River and the Sabine River. Its eastern boundary coincides with the western boundary of Unit 8. Its western boundary follows the Louisiana State Line in the Sabine River and Sabine Lake.

Vegetative Types

The Louisiana Coastal Marshes were subdivided into four vegetative types on a basis of the classification reported by Penfound and Hathaway (1938). The vegetation present along the transect lines was used in establishing the boundaries of the various types. The vegetative types (saline, brackish, intermediate, and fresh) follow a general east-west direction, parallel the coast, and are shown on a map (Figure 2) prepared by Chabreck, Joanen, and Palmisano (1968).

Vegetation Sampling

Vegetation was sampled in the Louisiana Coastal Marshes in August 1968. Samples were taken along 39 north-south transect lines equally spaced at 7.5 minutes of longitude along the coast. Two

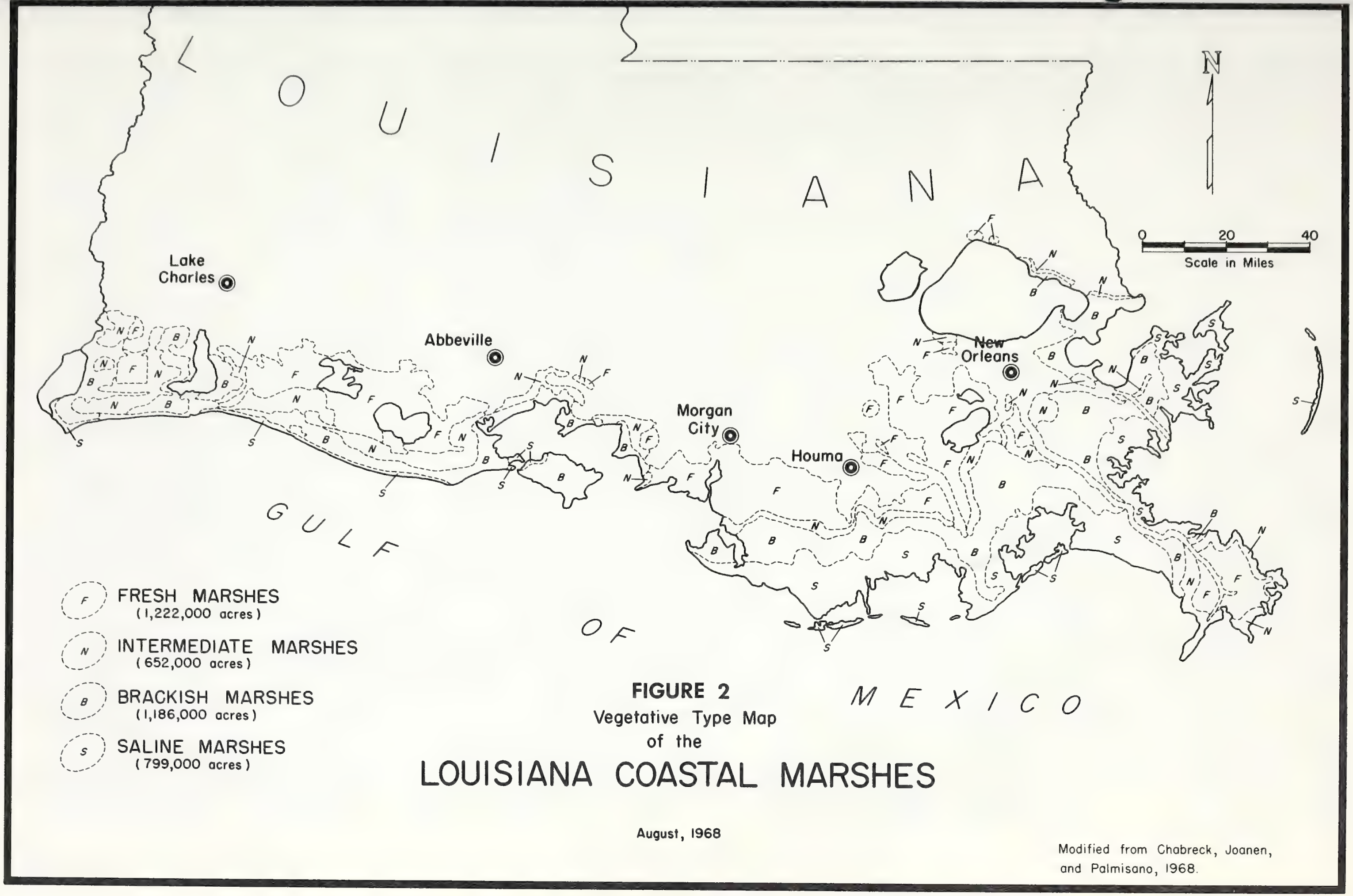


FIGURE 2
Vegetative Type Map
of the
LOUISIANA COASTAL MARSHES

August, 1968

Modified from Chabreck, Joanen, and Palmisano, 1968.

helicopters were employed for transportation, and vegetation estimates were made at 0.25-mile intervals along each transect line while hovering above the station. Landings were made at 2-mile intervals for collecting soil and water samples and for making ground measurements of the vegetation. A modification of the line-intercept method as described by Canfield (1941) was used for vegetation sampling.

Soil and Water Sampling

Soil and water samples were taken in August 1968 at 2-mile intervals along the transect lines and also in special areas not included by the routine landings. Soil samples were taken at depths ranging from the surface to 12 inches. This depth included the root zone for practically all marsh plants in the coastal area. Water samples were taken from free soil water.

Approximately 1 quart of soil was collected from each station and placed in a plastic bag. The plastic bag was then inserted inside a cloth bag to minimize the danger of accidental breakage. Water samples were collected and transported in 1-ounce glass jars. The station number was written on the bag for identification and the samples were stored in refrigeration at 35°F during the interval between collection and drying.

Soil Analysis

During the study 391 soil samples were collected in the coastal area for chemical analysis. Prior to the analysis each sample was weighed, air-dried, then reweighed to determine the original moisture content. The samples were dried at normal air temperature. Because of an extremely high moisture content, drying required several weeks.

The dried samples were analyzed by the Louisiana Soils Testing Laboratory at Louisiana State University. Tests included in the analysis were those for soil reaction (pH), total salts, phosphorus, potassium, calcium, magnesium, sodium, nitrogen, and carbon. Most analytical methods used are described in a bulletin by Brupbacher, Bonner, and Sedberry (1968).

The phosphorus concentrations of the soil samples were determined by colorimetric analysis (Stannous Chloride Reduction Method), as described by Page (1965). The phosphorus concentration was determined with a spectrophotometer which measured the intensity of blue color developed by the selective reduction of the phosphomolybid complex in an acid medium.

Organic carbon in the soils was determined by the dry combustion method described by Allison, Bollen, and Moodie (1965). A 0.15-gram sample of soil was transferred to a ceramic boat and placed in a combustion tube which had been preheated to 950° C. Purified oxygen was passed through the system in the presence of a platinum catalyst to convert the carbon evolved from the soil sample to carbon dioxide. The carbon dioxide gas was absorbed in pre-weighed

Pyrex glass bulbs containing ascarite. After evolution of the carbon dioxide the glass bulbs were again weighed and the weight of the CO_2 determined.

The percentage organic matter was computed from the information on organic carbon. The method as described by Wilson and Stoker (1932) for peat soils simply involves multiplying the percentage of organic carbon by the factor 1.724.

Correction Factor

Since marsh soils are characteristically wet, the ionic components were expressed on a wet-weight basis. Plants growing in the marsh are wetland species, and soil values presented for this area should reflect conditions under which the plants normally grow. A correction factor was determined for each sample and used to correct the analysis to wet weight. This correction factor was equal to the percent soil in the sample before drying. Items expressed on a wet-weight basis were: total salts, calcium, magnesium, phosphorus, potassium, and sodium.

Water Salinity Analysis

Samples of free soil water were analyzed for total salts by determining the electrical conductivity of the solution. Total salt was calculated by multiplying the electrical conductance at 25° C by the standard conversion factor 0.64, then by 1,000 to give the salinity in parts per thousand (Richards, 1954).

Surface Feature Description

The surface feature of each sampling station was listed on the field tally sheet in August 1968 while hovering over the station in a helicopter. Although much of the coastal area is marsh, other features are very important and greatly inflence environmental conditions in the marshes. Areas of particular interest other than marshes are the water bodies which are closely associated with the marshes.

Surface features used in classifying the coastal area were natural marsh, de-watered marsh, pond or lake, bay or sound, bayou or river, ditch or canal, swamp, and various dry land areas such as levees or spoil deposits, elevated bayou or lake banks, grassy ridges, timbered ridges, beach deposits, and miscellaneous high ground.

Computing Acreages

The acreage of the entire coastal area of Louisiana and the individual hydrologic units was determined by weighing maps of the areas. Each segment was weighed on a Mettler balance, Model B-5, to the nearest 0.10 mg. The acreage of the hydrologic units was then determined by weighing segments of the same map of known acreages and determining the weight-acreage relation.

The acreage of the various surface features within each hydrologic unit was determined from the field data. The percentage frequency with which the stations occurred in each surface feature was used as the factor for computing acreages in the hydrologic unit involved.

Computing the Number of Ponds and Lakes

Surface features were checked and classified at 7,127 stations along the Louisiana coast. The percentage frequency of stations occupied by ponds and lakes was multiplied by the total acreage of the area sampled to calculate the total acreage of ponds and lakes. The size of the area sampled was 7,823,386 acres (Chabreck, 1970).

The acreage of ponds and lakes in the coastal area was also calculated by size classes. This was done by first determining the percentage frequency of ponds in each size class and multiplying the percentage value by the total acreage in ponds and lakes. The values obtained were the total acreages in ponds and lakes of different size classes. Ten size classes were used; they ranged from ponds less than 0.01 acre to lakes larger than 64,000 acres.

The number of ponds and lakes in each size class was computed from the total acreage. In this procedure the acreage of each size class was divided by the mid-point value of the size class.

RESULTS

Coastal Surface Features

The acreages of the various hydrologic units are shown in Table 3. The total acreage of the Louisiana Coastal Region was 7,823,386 acres, according to the study. This included both land and water areas. Of this amount, natural marshes made up 2,459,555 acres, or slightly less than one-third of the area. The brackish and fresh vegetative types were of about equal size, making up a total of 61 percent of the natural marshes. The saline vegetative type made up 25 percent and the intermediate comprised only 14 percent of the marsh area.

The acreage of the various surface features of each hydrologic unit is shown by vegetative type in Table 4.

Hydrologic Unit 1 was the largest (Table 3); however, a great portion of this was taken up by water bodies such as Chandeleur Sound, Lake Pontchartrain, and Lake Borgne. The largest area of natural marshes was found in Hydrologic Unit 5, which included the Terrebonne Parish marshes. Hydrologic Units 4 and 8 also encompassed large areas of natural marsh.

Almost one-fourth of the entire coastal area consisted of ponds and lakes (Table 3). Ponds and lakes were classified into 10 size classes, and all size classes were well represented (Table 5). A general increase in total acreage occupied was noted with each increase in size class.

The study revealed a total of 5.3 million ponds and lakes in the coastal area (Table 5). Of these, over one-half were less than 0.01 acre in size. The number of ponds and lakes decreased with increases in size classes. An interesting point in this regard was that the ponds 0.01 to 0.1 acre in size outnumbered those less than 0.01 acre in size in Hydrologic Units 7, 8, and 9 (Table 7). These hydrologic units occupy the western portion of the Louisiana coast and include the Chenier Plain. The acreage of ponds and lakes varied greatly between units, with Hydrologic Unit 1 having the largest acreage (Table 6).

The brackish vegetative type had the greatest density of ponds and lakes (Table 8). This type exceeded the others in practically all pond and lake size classes on a per unit area basis. The fresh type ranked second and the saline type had the lowest density of ponds and lakes.

Vegetation

Plant coverage and plant species composition were determined for the natural marshes and for ponds and lakes of the coastal region.

Natural Marshes

Plant coverage refers to the degree to which a marsh is covered with vegetation, and is shown for each vegetative type and hydrologic unit in Table 9. In general, fresh marshes had the highest plant coverage, with the exception of the saline type in Hydrologic Units 8 and 9 and the intermediate type in Unit 3.

A total of 118 species of vascular plants were found at sampling points along the transect lines. The species present in greatest amounts were *Spartina patens,* making up one-fourth of the vegetation in the coastal marshes. Other major species were *Spartina alterniflora, Panicum hemitomon, Distichlis spicata,* and *Sagittaria falcata.*

The species composition was determined for the four vegetative types (Table 10). The saline vegetative type was dominated by *Spartina alterniflora* along with *Distichlis spicata, Juncus roemerianus,* and *Spartina patens.* The major species in the brackish and intermediate vegetative types was *Spartina patens. Distichlis spicata* was also abundant in the brackish type and *Phragmites communis* and *Sagittaria falcata* in the intermediate type. The fresh vegetative type included 93 species, with *Panicum hemitomon* being dominant. Other major fresh marsh plants were *Sagittaria falcata, Eleocharis* sp., and *Alternanthera philoxeroides.*

The species composition was also determined by vegetative type for each hydrologic unit (Table 11). The species listed are those making up 1.0 percent or more of the plants present. Species comprising less than 1.0 percent were grouped under "other species." All species encountered during the study and their percent composition of the vegetative types are shown in Table 10.

Ponds and Lakes

Percent plant coverage of pond and lake bottoms was inversely proportional to water salinity (Table 12). Ponds and lakes of the fresh vegetative type had the greatest plant coverage, followed by the intermediate, brackish, and saline types in descending order. No vegetation was found in ponds and lakes sampled in the saline vegetative type. Likewise, no vegetation was found in any lake greater than 3,200 acres in size.

Thirty species of vascular plants were found at the sampling stations in ponds and lakes. In addition, an alga, *Chara vulgaris,* was included because of its abundance and use as food by waterfowl. As with plant coverage, the number of species was inversely related to water salinity. Of the 31 species encountered, 29 were found in the fresh vegetative type, 10 in the intermediate, 6 in the brackish, and none in the saline (Table 13).

A brackish water species, *Ruppia maritima,* was the dominant plant along the entire Louisiana coast in ponds and lakes. Other major species were *Lemna minor, Myriophyllym spicatum, Chara vulgaris, Ceratophyllum demersum,* and *Eleocharis parvula* (Table 13).

The plant species composition of ponds and lakes of different size classes is shown in Table 14. A comparison of the number of plant species by pond size shows that the 1- to 10-acre size class contained the greatest number of species. The number of species declined progressively both below and above this class.

Lakes larger than 1 square mile in size usually contained few plants. Several of the larger lakes, such as Lake Pontchartrain, contained aquatic plants in the shallow water around the shoreline. However, no plants occurred at the sample stations, indicating a very narrow distribution. Additional information on ponds and lakes of the Louisiana Coastal Region and their value to fish and wildlife are presented in a separate report (Chabreck, 1971).

Soil and Water Summary by Plant Species

The plant species present at each soil and water sampling station were recorded on the tally sheet. The conditions under which each species was growing was determined by summarizing the soil and water variables at stations where each species occurred.

Only species which occurred at three or more sampling stations were included in this summation. Of the 118 species encountered along the transect lines, 83 met this requirement. The results of this segment of the investigation are listed in Table 15.

Soil and Water Summary by Location

The results of the soil and water analyses are shown in Tables 16 through 30 and are grouped by hydrologic unit and vegetative type. The values for all variables measured are shown for each hydrologic unit by vegetative type in Tables 16 through 19. The values for individual variables are summarized by vegetative types and hydrologic units in Tables 20 through 30.

Two principal factors affecting plant distribution and growth are salinity and soil organic matter (Palmisano and Chabreck, 1972). Water salinity and total soil salts were greatest at the Gulf of Mexico and decreased inland (Figure 3); however, soil organic matter was lowest along the coastline and increased inland (Figure 4).

Plant nutrients were highest in the saline vegetative type and decreased inland, with lowest concentrations in the fresh type. Calcium was the only nutrient that exhibited only small differences between vegetative types. Soil reaction (pH) was slightly lower in the fresh vegetative type.

Table 3. Acreages contained in surface features of hydrologic units of the Louisiana Coastal Region

Surface Feature	Hydrologic Unit									
	1	2	3	4	5	6	7	8	9	Total
	Acres									
Marshes:										
Natural marsh	261,198	143,850	81,738	469,311	583,101	40,554	271,087	396,353	212,362	2,459,554
De-watered marsh	18,300	2,373	- -	27,748	18,226	- -	4,511	54,773	39,858	165,789
Water Bodies:										
Ponds and lakes	603,306	49,517	95,391	292,056	228,390	20,825	33,904	230,747	228,552	1,782,688
Bays and sounds	1,019,066	212,260	122,625	108,841	320,082	64,668	332,127	- -	- -	2,179,669
Bayous and rivers	26,040	5,888	17,004	43,795	16,965	3,288	4,781	4,174	3,262	125,197
Canals and ditches	9,234	7,075	12,476	5,198	9,365	1,095	5,328	3,849	3,855	57,475
Swamp	- -	- -	- -	15,419	22,853	21,920	8,256	- -	- -	68,448
Dry Land[a]	263,835	27,108	27,234	327,428	202,172	4,383	54,204	26,456	51,746	984,566
TOTAL	2,200,979	448,071	356,468	1,289,796	1,401,154	156,733	714,198	716,352	539,635	7,823,386

[a] Includes active beaches, cheniers, spoil deposits, ridges and elevated bayou and lake banks.

Table 4. Acreage of surface features by vegetative types and hydrologic units of the Louisiana Coastal Region

	Vegetative Type				
Surface Feature	Saline	Brackish	Intermediate	Fresh	Non-marsh
	Acres				
	Hydrologic Unit 1				
Marshes:					
Natural marsh	91,463	141,152	16,930	11,653	- -
De-watered marsh	- -	- -	- -	- -	18,300
Water Bodies:					
Ponds and lakes	53,427	330,455	117,627	101,797	- -
Bays and sounds	968,058	51,008	- -	- -	- -
Bayous and rivers	10,553	14,291	600	596	- -
Canals and ditches	5,277	2,638	1,319	- -	- -
Swamp	- -	- -	- -	- -	- -
Dry Land[a]	- -	- -	- -	- -	263,835
TOTAL	1,128,778	539,544	136,476	114,046	282,135
	Hydrologic Unit 2				
Marshes:					
Natural marsh	43,630	89,632	10,588	- -	- -
De-watered marsh	- -	- -	- -	- -	2,373
Water Bodies:					
Ponds and lakes	5,887	43,630	- -	- -	- -
Bays and sounds	212,260	- -	- -	- -	- -
Bayous and rivers	1,187	4,701	- -	- -	- -
Canals and ditches	1,187	4,701	1,187	- -	- -
Swamp	- -	- -	- -	- -	- -
Dry Land[a]	- -	- -	- -	- -	27,108
TOTAL	264,151	142,664	11,775	- -	29,481
	Hydrologic Unit 3				
Marshes:					
Natural marsh	- -	17,039	36,324	28,375	- -
De-watered marsh	- -	- -	- -	- -	- -
Water Bodies:					
Ponds and lakes	- -	10,231	10,231	74,929	- -
Bays and sounds	11,336	85,160	18,180	7,949	- -
Bayous and rivers	- -	1,141	4,427	11,336	- -
Canals and ditches	- -	4,527	4,527	3,422	- -
Swamp	- -	- -	- -	- -	- -
Dry Land[a]	- -	- -	- -	- -	27,234
TOTAL	11,336	118,098	73,789	126,011	27,234

(Continued)

Table 4. (Continued)

Surface Feature	Vegetative Type Saline	 Brackish	 Intermediate	 Fresh	 Non-marsh
	------------	------------	Acres	------------	------------
		Hydrologic Unit 4			
Marshes:					
Natural marsh	144,214	125,296	20,084	179,717	- -
De-watered marsh	- -	- -	- -	- -	27,748
Water Bodies:					
Ponds and lakes	61,547	96,920	3,498	130,091	- -
Bays and sounds	108,841	- -	- -	- -	- -
Bayous and rivers	14,253	11,791	3,498	14,253	- -
Canals and ditches	2,332	1,166	200	1,500	- -
Swamp	- -	- -	- -	- -	15,419
Dry Land[a]	- -	- -	- -	- -	327,428
TOTAL	331,187	235,173	27,280	325,561	370,595
		Hydrologic Unit 5			
Marshes:					
Natural marsh	184,086	135,996	37,714	225,305	- -
De-watered marsh	- -	- -	- -	- -	18,226
Water Bodies:					
Ponds and lakes	99,403	68,559	4,487	55,941	- -
Bays and sounds	268,768	39,958	11,356	- -	- -
Bayous and rivers	7,992	5,608	1,122	2,243	- -
Canals and ditches	1,122	2,243	1,200	4,800	- -
Swamp	- -	- -	- -	- -	22,853
Dry Land[a]	- -	- -	- -	- -	202,172
TOTAL	561,371	252,364	55,879	288,289	243,251
		Hydrologic Unit 6			
Marshes:					
Natural marsh	- -	- -	3,288	37,266	- -
De-watered marsh	- -	- -	- -	- -	- -
Water Bodies:					
Ponds and lakes	- -	- -	- -	20,825	- -
Bays and sounds	- -	- -	- -	64,668	- -
Bayous and rivers	- -	- -	- -	3,288	- -
Canals and ditches	- -	- -	- -	1,095	- -
Swamp	- -	- -	- -	- -	21,920
Dry Land[a]	- -	- -	- -	- -	4,383
TOTAL	- -	- -	3,288	127,142	26,303

(Continued)

Table 4. (Continued)

Surface Feature	Vegetative Type				
	Saline	Brackish	Intermediate	Fresh	Non-marsh
	Acres				
	Hydrologic Unit 7				
Marshes:					
Natural marsh	3,383	134,416	85,851	47,437	- -
De-watered marsh	- -	- -	- -	- -	4,511
Water Bodies:					
Ponds and lakes	- -	24,881	6,767	2,256	- -
Bays and sounds	9,022	271,765	6,159	45,181	- -
Bayous and rivers	- -	2,256	1,125	1,400	- -
Canals and ditches	- -	2,028	2,300	1,000	- -
Swamp	- -	- -	- -	- -	8,256
Dry Land[a]	- -	- -	- -	- -	54,204
TOTAL	12,405	435,346	102,202	97,274	66,971
	Hydrologic Unit 8				
Marshes:					
Natural marsh	20,379	80,300	76,439	219,235	- -
De-watered marsh	- -	- -	- -	- -	54,773
Water Bodies:					
Ponds and lakes	1,287	21,666	10,225	197,569	- -
Bays and sounds	- -	- -	- -	- -	- -
Bayous and rivers	- -	1,000	600	2,574	- -
Canals and ditches	- -	750	525	2,574	- -
Swamp	- -	- -	- -	- -	- -
Dry Land[a]	- -	- -	- -	- -	26,456
TOTAL	21,666	103,716	87,789	421,952	81,229
	Hydrologic Unit 9				
Marshes:					
Natural marsh	6,455	84,073	91,658	30,176	- -
De-watered marsh	- -	- -	- -	- -	39,858
Water Bodies:					
Ponds and lakes	- -	178,958	30,176	19,418	- -
Bays and sounds	- -	- -	- -	- -	- -
Bayous and rivers	- -	1,227	1,360	675	- -
Canals and ditches	- -	1,675	1,880	300	- -
Swamp	- -	- -	- -	- -	- -
Dry Land[a]	- -	- -	- -	- -	51,746
TOTAL	6,455	265,933	125,074	50,569	91,604

[a] Includes active beaches, cheniers, spoil deposits, ridges and elevated bayou and lake banks.

Table 5. Number and area of ponds and lakes along the Louisiana coast by size classes

Size Classes (Acres)	No. Ponds and Lakes	Total Area Included (Acres)
<.01	2,950,000	28,340
.01 - .10	1,889,000	75,230
.10 - 1.0	425,800	132,275
1.0 - 10	43,460	123,360
10 - 80	5,472	148,140
80 - 640	722	150,640
640 - 3,200	149	222,300
3,200 - 16,000	15	114,800
16,000 - 64,000	7	359,200
>64,000	1	428,403
Total	5,314,626	1,782,688

Table 6. Acreage of ponds and lakes in hydrologic units and vegetative types along the Louisiana coast

Hydrologic Unit	Vegetative Type				
	Saline	Brackish	Intermediate	Fresh	Total
	Acres				
1	53,427	330,455	117,627	101,797	603,306
2	5,887	43,630	0	0	49,517
3	0	10,231	10,231	74,929	95,391
4	61,547	96,920	3,498	130,091	292,056
5	99,403	68,559	4,487	55,941	228,390
6	0	0	0	20,825	20,825
7	0	24,881	6,767	2,256	33,904
8	1,287	21,666	10,225	197,569	230,747
9	0	178,958	30,176	19,418	228,552
Total	221,551	775,300	183,011	602,826	1,782,688

Table 7. Number of ponds and lakes of various size classes in hydrologic units along the Louisiana coast

Pond Size Class (Acres)	Hydrologic Unit									
	1	2	3	4	5	6	7	8	9	Total
<.01	257,000	122,000	356,000	814,000	824,000	108,000	115,000	248,000	106,000	2,950,000
.01 - 0.1	35,000	111,000	141,000	512,000	383,000	22,000	232,000	298,000	155,000	1,889,000
0.1 - 1.0	19,750	24,800	14,950	105,650	79,100	3,100	19,400	66,450	92,600	425,800
1.0 - 10	4,360	2,990	3,930	7,760	6,550	800	1,290	9,240	6,540	43,460
10 - 80	547	309	769	546	1,402	102	321	446	1,030	5,472
80 - 640	162	40	151	149	119	15	28	83	38	785
640 - 3,200	5	17	8	37	42	8	5	12	15	149
3,200 - 16,000	0	1	0	6	8	0	0	0	0	15
16,000 - 64,000	1	0	0	2	0	0	0	2	2	7
>64,000	1	0	0	0	0	0	0	0	0	1

Table 8. Density of ponds and lakes of various size classes in vegetative types along the Louisiana coast

Pond and Lake Size Classes (Acres)	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	Number Per Hundred Thousand Acres			
<.01	27,700.24	118,841.70	55,952.21	59,181.16
.01 - 0.1	16,748.98	62,162.16	45,024.04	47,637.37
0.1 - 1.0	4,702.60	14,139.00	10,432.76	9,796.83
1.0 - 10	700.02	1,376.06	759.14	1,070.49
10 - 80	132.17	179.54	73.15	108.82
80 - 640	30.17	12.36	2.62	25.09
640 - 3,200	5.15	3.24	0	4.54
3,200 - 16,000	.54	.62	0	.15
16,000 - 64,000	0	.23	0	.31
> 64,000	0	.08	0	0

Table 9. Plant coverage[a] of vegetative types within hydrologic units of the Louisiana Coastal Marshes

Hydrologic Unit	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	Percent			
1	75.86	73.80	69.70	99.12
2	69.41	80.87	61.25	- -
3	- -	54.53	76.86	69.02
4	75.02	75.25	77.06	82.43
5	53.10	74.11	80.53	82.81
6	- -	- -	68.00	87.42
7	73.34	74.91	81.40	83.46
8	80.00	68.93	78.14	74.68
9	82.34	65.12	68.19	71.03
Mean	73.5	70.2	75.3	80.6

[a] Includes only natural marshes.

Table 10. Plant species composition of vegetative types in the Louisiana Coastal Marshes

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	----------	Percent	----------	----------
Acnida alabamensis	- -	.10	.30	.02
Aeschynomene virginica	- -	- -	- -	.07
Alternanthera philoxeroides	- -	- -	2.47	5.34
Aster sp.	- -	.08	.44	.13
Avicennia nitida	.60	- -	- -	- -
Azolla caroliniana	- -	- -	- -	.13
Baccharis halimifolia	- -	.10	.56	.02
Bacopa caroliniana	- -	- -	.28	.34
Bacopa monnieri	- -	.92	4.75	1.44
Bacopa rotundifolia	- -	.11	.32	- -
Batis maritima	4.41	- -	- -	- -
Bidens laevis	- -	- -	- -	.08
Borrichia frutescens	.67	.11	- -	- -
Brasenia schreberi	- -	- -	- -	.67
Caboma caroliniana	- -	- -	- -	.71
Carex sp.	- -	- -	- -	.02
Centella erecta	- -	- -	.16	.12
Cephalanthus occidentalis	- -	- -	- -	.21
Ceratophyllum demersum	- -	- -	- -	1.50
Cladium jamaicense	- -	- -	- -	.84
Colocasia antiquorum	- -	- -	- -	.39
Cuscuta indecora	- -	.02	- -	- -
Cynodon dactylon	- -	- -	- -	.10
Cyperus compressus	- -	- -	- -	.02
Cyperus odoratus	- -	.84	2.18	1.56
Daubentonia texana	- -	- -	.04	.17
Decodon verticillatus	- -	- -	- -	.51
Dichromena colorata	- -	- -	- -	.03
Distichlis spicata	14.27	13.32	.36	.13
Dryopteris thelypteris var. haliana	- -	- -	- -	.44
Echinochloa walteri	- -	.36	2.72	.77
Eichornia crassipes	- -	- -	- -	1.43
Eleocharis parvula	- -	2.46	.49	.54
Eleocharis sp.	- -	.82	3.28	10.74
Eupatorium capillifolium	- -	- -	- -	.05
Eupatorium sp.	- -	- -	.08	.03
Fimbristylis castanea	.04	.11	.12	- -
Gerardia maritima	.01	.08	- -	- -
Heliotropium curassavicum	- -	.02	- -	- -
Hibiscus lasiocarpus	- -	- -	.10	.05
Hydrocotyle bonariensis	- -	- -	- -	.02
Hydrocotyle ranunculoides	- -	- -	- -	.11
Hydrocotyle umbellata	- -	- -	- -	1.93
Hymenocallis occidentalis	- -	- -	.04	.14
Hypericum virginicum	- -	- -	- -	.07
Ipomoea stolonifera	- -	- -	- -	.03

(Continued)

Table 10. (Continued)

Species	Vegetative Type Saline	 Brackish	 Intermediate	 Fresh
	-------------------	Percent	-------------------	
Ipomoea sagittata	- -	.13	.84	.19
Iva frutescens	.03	.10	- -	- -
Juncus effusus	- -	- -	- -	.11
Juncus roemerianus	10.10	3.93	.72	.60
Jussiaea diffusa	- -	- -	- -	.24
Jussiaea sp.	- -	- -	- -	.84
Kosteletzkya virginica	- -	.02	.18	.07
Lemna minor	- -	.02	.16	2.31
Leptochloa fascicularis	- -	.32	2.17	.49
Leptochloa filiformis	- -	- -	.04	- -
Limnobium spongia	- -	- -	- -	.16
Lippia nodiflora	- -	- -	- -	.06
Lycium carolinianum	.07	- -	- -	- -
Lythrum lineare	.01	.16	.18	.07
Myrica cerifera	- -	- -	- -	.16
Myriophyllum spicatum	- -	.15	.44	1.56
Myriophyllum heterophyllum	- -	- -	- -	.19
Najas quadalupensis	- -	- -	1.03	1.07
Nelumbo lutea	- -	- -	- -	.54
Nymphaea odorata/tuberosa	- -	- -	- -	1.15
Nymphoides aquaticum	- -	- -	- -	.11
Osmunda regalis	- -	- -	.16	.43
Ottelia alismoides	- -	- -	- -	.03
Panicum hemitomon	- -	- -	.76	25.62
Panicum repens	- -	- -	.92	.24
Panicum virgatum	- -	.14	2.51	.45
Panicum sp.	- -	- -	- -	.10
Paspalum dissectum	- -	- -	.40	.42
Paspalum vaginatum	- -	1.38	4.46	.35
Philoxerus vermicularis	- -	- -	.08	.01
Phragmites communis	- -	.31	6.63	2.54
Pluchea foetida	- -	- -	- -	.02
Pluchea camphorata	- -	.87	2.26	.36
Polygonum sp.	- -	- -	- -	.56
Pontederia cordata	- -	- -	- -	.07
Potamogeton nodosus	- -	- -	.28	.03
Potamogeton pusillus	- -	- -	.24	.62
Ruppia maritima	- -	3.83	.64	- -
Sacciolepis striata	- -	- -	- -	.06
Sagittaria falcata	- -	- -	6.47	15.15
Sagittaria latifolia	- -	- -	- -	.21
Sagittaria platyphylla	- -	- -	- -	.23
Sagittaria sp.	- -	- -	.08	- -
Salicornia bigelovii	.13	- -	- -	- -
Salicornia virginica	.63	- -	- -	- -
Salix nigra	- -	- -	- -	.06
Saururus cernuus	- -	- -	- -	.16
Scirpus americanus	- -	- -	1.27	.13
Scirpus californicus	- -	- -	1.83	.42
Scirpus olneyi	- -	4.97	3.26	.45
Scirpus robustus	.66	1.78	.68	- -

(Continued)

Table 10. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	----------	Percent	----------	
Scirpus validus	- -	.08	- -	- -
Sesbania exaltata	- -	.06	.20	- -
Sesuvium portulacastrum	- -	.04	- -	- -
Setaria glauca	- -	.06	- -	- -
Setaria magna	- -	- -	- -	.03
Solidago sp.	- -	- -	.04	.08
Spartina alterniflora	62.14	4.77	.86	- -
Spartina cynosuroides	- -	.89	1.19	.02
Spartina patens	5.99	55.22	34.01	3.74
Spartina spartineae	.01	.04	1.48	- -
Spirodela polyrhiza	- -	- -	- -	.20
Suaeda linearis	.23	- -	- -	- -
Taraxacum officinale	- -	- -	.02	- -
Taxodium distichum	- -	- -	- -	.02
Typha spp.	- -	- -	.98	1.57
Utricularia cornuta	- -	- -	- -	1.68
Utricularia subulata	- -	- -	- -	.21
Vallisneria americana	- -	.08	- -	- -
Vigna repens	- -	1.20	3.84	1.43
Woodwardia virginica	- -	- -	- -	.28
Zizaniopsis miliacea	- -	- -	- -	1.20

Table 11. Plant species composition of vegetative types by hydrologic unit of the Louisiana Coastal Marshes[a]

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	------------------- Percent -------------------			
	Hydrologic Unit 1			
Acnida alabamensis	- -	- -	- -	1.12
Bacopa monnieri	- -	- -	- -	6.74
Cladium jamaicense	- -	- -	- -	31.46
Cyperus odoratus	- -	- -	- -	2.25
Cyperus sp.	- -	- -	2.21	- -
Distichlis spicata	10.47	7.09	- -	- -
Ipomoea sagittata	- -	- -	- -	2.25
Juncus effusus	- -	- -	- -	2.25
Juncus roemerianus	19.36	4.48	- -	- -
Osmunda regalis	- -	- -	- -	13.48
Panicum virgatum	- -	- -	- -	1.12
Panicum sp.	- -	- -	- -	8.99
Phragmites communis	- -	- -	- -	4.50
Sagittaria falcata	- -	- -	- -	11.24
Sagittaria sp.	- -	- -	2.21	- -
Scirpus olneyi	- -	3.11	9.93	- -
Scirpus robustus	- -	4.35	- -	- -
Spartina alterniflora	65.65	5.72	- -	- -
Spartina cynosuroides	- -	3.66	- -	- -
Spartina patens	1.81	67.99	84.99	- -
Taxodium distichum	- -	- -	- -	1.12
Typha spp.	- -	- -	- -	6.74
Vigna repens	- -	- -	- -	6.74
Other species[b]	2.71	3.60	.66	- -
	Hydrologic Unit 2			
Batis maritima	6.07	- -	- -	- -
Distichlis spicata	13.78	6.80	- -	- -
Echinochloa walteri	- -	1.11	- -	- -
Eleocharis parvula	- -	4.20	- -	- -
Eleocharis sp.	- -	- -	8.50	- -
Juncus roemerianus	- -	2.78	- -	- -
Pluchea camphorata	13.24	3.19	1.36	- -
Ruppia maritima	- -	1.11	- -	- -
Scirpus olneyi	1.95	5.27	16.33	- -
Scirpus robustus	- -	1.15	- -	- -
Spartina alterniflora	61.14	6.13	- -	- -
Spartina patens	3.50	63.87	71.43	- -
Vigna repens	- -	2.04	- -	- -
Other species[b]	.32	2.35	.66	- -

(Continued)

Table 11. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	Percent			
	Hydrologic Unit 3			
Alternanthera philoxeroides	- -	- -	2.60	8.69
Bacopa monnieri	- -	- -	10.41	- -
Cyperus odoratus	- -	- -	- -	- -
Distichlis spicata	- -	8.54	- -	- -
Echinochloa walteri	- -	- -	1.49	- -
Eichornia crassipes	- -	- -	- -	5.53
Eleocharis parvula	- -	2.85	- -	- -
Eleocharis sp.	- -	- -	3.12	- -
Lemna minor	- -	- -	- -	7.85
Myriophyllum spicatum	- -	- -	4.09	25.29
Panicum hemitomon	- -	- -	2.97	- -
Panicum repens	- -	- -	8.55	3.95
Phragmites communis	- -	10.82	43.64	37.30
Pluchea camphorata	- -	- -	2.16	- -
Potamogeton pusillus	- -	- -	1.49	2.90
Ruppia maritima	- -	- -	1.49	- -
Sagittaria falcata	- -	- -	4.09	- -
Sagittaria platyphylla	- -	- -	- -	3.69
Saururus cernuus	- -	- -	- -	2.11
Scirpus americanus	- -	- -	3.72	- -
Scirpus robustus	- -	7.59	- -	- -
Scirpus validus	- -	3.79	- -	- -
Spartina alterniflora	- -	58.44	6.17	- -
Spartina patens	- -	6.64	1.49	- -
Spirodela polyrhiza	- -	- -	- -	2.69
Other species[b]	- -	1.33	2.52	- -
	Hydrologic Unit 4			
Alternanthera philoxeroides	- -	- -	- -	3.43
Bacopa monnieri	- -	- -	23.97	1.82
Batis maritima	3.08	- -	- -	- -
Cyperus odoratus	- -	- -	5.34	3.21
Decodon verticillatus	- -	- -	- -	1.16
Distichlis spicata	10.05	28.96	3.05	- -
Echinochloa walteri	- -	- -	- -	2.15
Eichornia crassipes	- -	- -	- -	1.99
Eleocharis parvula	- -	5.49	- -	- -
Eleocharis sp.	- -	1.40	2.29	12.31
Ipomoea sagittata	- -	- -	1.53	- -
Juncus roemerianus	14.90	3.26	- -	- -
Panicum hemitomon	- -	- -	- -	41.35
Pluchea camphorata	- -	- -	16.79	- -
Polygonum sp.	- -	- -	- -	1.60
Sagittaria falcata	- -	- -	3.82	17.42
Salicornia virginica	1.19	- -	- -	- -
Scirpus olneyi	- -	2.26	- -	1.48
Spartina alterniflora	62.79	9.03	- -	- -
Spartina patens	7.77	45.84	41.99	- -
Typha spp.	- -	- -	- -	2.59
Vigna repens	- -	- -	- -	1.16
Zizaniopsis miliaceae	- -	- -	- -	1.36
Other species[b]	.22	3.76	1.22	6.97

(Continued)

Table 11. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	------------------- Percent ------------------			
	Hydrologic Unit 5			
Alternanthera philoxeroides	- -	- -	- -	2.42
Aster sp.	- -	- -	1.12	- -
Avicennia nitida	1.52	- -	- -	- -
Bacopa monnieri	- -	- -	3.72	2.73
Batis maritima	6.58	- -	- -	- -
Cyperus odoratus	- -	2.31	2.98	1.92
Decodon verticillatus	- -	- -	- -	1.10
Distichlis spicata	11.66	13.09	1.86	- -
Dryopteris thelypteris	- -	- -	- -	1.43
Echinochloa walteri	- -	- -	2.60	- -
Eleocharis sp.	- -	1.93	1.27	18.03
Hydrocotyle umbellata	- -	- -	- -	4.32
Ipomoea sagittata	- -	- -	1.12	- -
Juncus roemerianus	3.69	- -	- -	- -
Leptochloa fascicularis	- -	- -	9.23	- -
Najas quadalupensis	- -	- -	3.35	- -
Osmunda regalis	- -	- -	1.49	- -
Panicum hemitomon	- -	- -	4.09	42.17
Paspalum vaginatum	- -	- -	2.98	- -
Phragmites communis	- -	- -	1.49	- -
Pluchea comphorata	- -	- -	3.12	1.19
Sagittaria falcata	- -	- -	2.45	7.67
Scirpus olneyi	- -	6.57	7.07	- -
Scirpus validus	- -	1.50	- -	- -
Spartina alterniflora	67.73	2.08	- -	- -
Spartina cynosuroides	- -	1.13	- -	- -
Spartina patens	6.81	63.39	34.23	1.22
Typha spp.	- -	- -	5.95	1.58
Vigna repens	- -	4.08	7.07	1.04
Zizaniopsis miliaceae	- -	- -	- -	3.18
Other species[b]	2.01	3.92	2.81	10.00
	Hydrologic Unit 6			
Alternanthera philoxeroides	- -	- -	- -	2.85
Cladium jamaicense	- -	- -	- -	1.43
Colocasia antiquorum	- -	- -	- -	5.71
Eleocharis sp.	- -	- -	4.90	3.28
Jussiaea sp.	- -	- -	- -	2.64
Panicum hemitomon	- -	- -	- -	19.63
Panicum virgatum	- -	- -	- -	6.43
Paspalum dissectum	- -	- -	- -	2.14
Phragmites communis	- -	- -	- -	2.50
Sagittaria falcata	- -	- -	4.90	27.91
Spartina cynosuroides	- -	- -	9.81	- -
Spartina patens	- -	- -	68.63	- -
Typha spp.	- -	- -	- -	9.43
Vigna repens	- -	- -	11.76	13.20
Other species[b]	- -	- -	- -	2.85

(Continued)

Table 11. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	------------------- Percent			------------------
	Hydrologic Unit 7			
Alternanthera philoxeroides	- -	- -	- -	3.44
Aster sp.	- -	- -	1.30	- -
Batis maritima	18.18	- -	- -	- -
Borrichia frutescens	9.10	- -	- -	- -
Cladium jamaicense	- -	- -	- -	4.01
Colocasia antiquorum	- -	- -	- -	1.15
Cyperus odoratus	- -	1.12	- -	- -
Distichlis spicata	- -	5.16	- -	- -
Echinochloa walteri	- -	- -	4.05	1.15
Eleocharis sp.	- -	- -	5.19	8.60
Hydrocotyle umbellata	- -	- -	- -	5.16
Hymenocallis occidentalis	- -	- -	- -	1.43
Ipomoea sagittata	- -	- -	2.11	- -
Juncus effusus	27.27	14.59	1.62	10.60
Panicum hemitomon	- -	- -	- -	2.00
Panicum virgatum	- -	1.03	8.59	4.58
Paspalum dissectum	- -	- -	1.62	1.15
Paspalum vaginatum	- -	1.24	1.95	- -
Phragmites communis	- -	- -	1.46	- -
Pluchea camphorata	- -	- -	2.11	- -
Sacciolepis striata	- -	- -	- -	2.29
Sagittaria falcata	- -	- -	12.64	24.06
Scirpus validus	- -	11.11	5.51	- -
Scirpus robustus	18.18	1.12	- -	- -
Spartina alterniflora	27.27	- -	- -	- -
Spartina cynosuroides	- -	1.01	3.41	1.15
Spartina patens	- -	56.70	30.63	19.20
Typha spp.	- -	- -	2.27	1.43
Vigna repens	- -	2.81	8.59	- -
Woodwardia virginica	- -	- -	1.62	5.44
Other species[b]	- -	4.11	5.33	3.16
	Hydrologic Unit 8			
Aeschynomene virginica	- -	- -	- -	1.71
Alternanthera philoxeroides	- -	- -	8.31	9.46
Bacopa caroliniana	- -	- -	1.28	1.14
Bacopa monnieri	- -	- -	4.05	- -
Bacopa rotundifolia	- -	- -	1.70	- -
Borrichia frutescens	4.69	- -	- -	- -
Brasenia schreberi	- -	- -	- -	1.71
Cabomba caroliniana	- -	- -	- -	1.01
Cyperus odoratus	- -	- -	6.17	- -
Distichlis spicata	68.75	27.87	- -	- -
Echinochloa walteri	- -	2.08	5.54	- -
Eleocharis parvula	- -	1.61	- -	- -
Eleocharis sp.	- -	- -	- -	5.60
Gerardia maritima	- -	1.38	- -	- -
Jussiaea sp.	- -	- -	- -	1.79
Leptochloa fascicularis	- -	- -	2.98	- -

(Continued on Page 38)

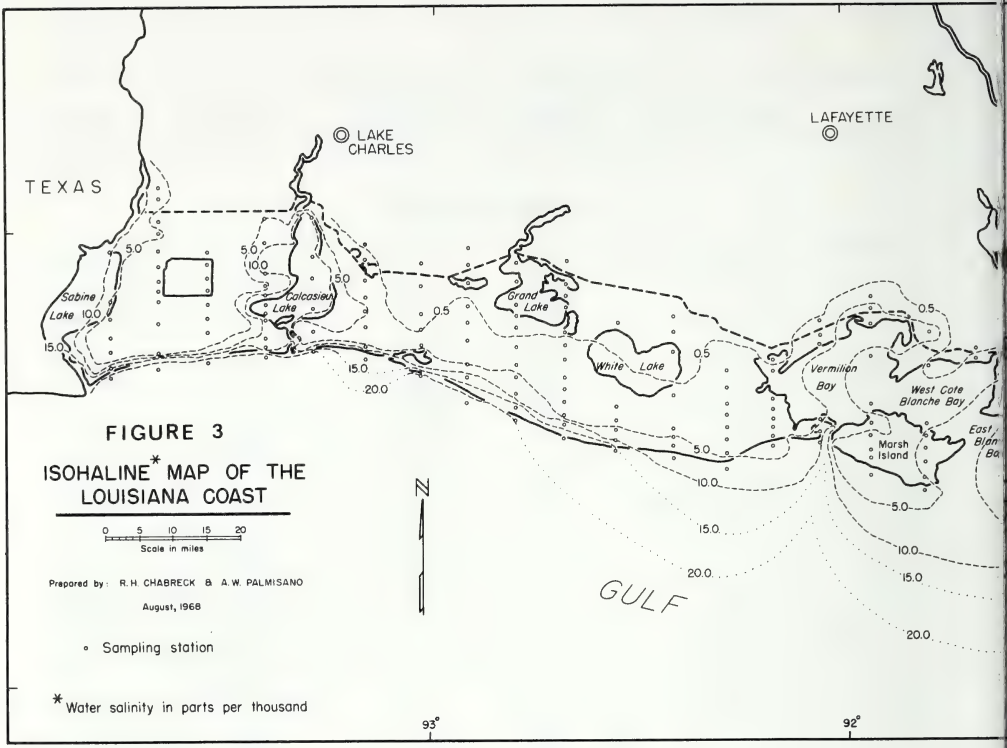


FIGURE 3

ISOHALINE* MAP OF THE LOUISIANA COAST

0 5 10 15 20
Scale in miles

Prepared by: R. H. CHABRECK & A. W. PALMISANO
August, 1968

∘ Sampling station

*Water salinity in parts per thousand

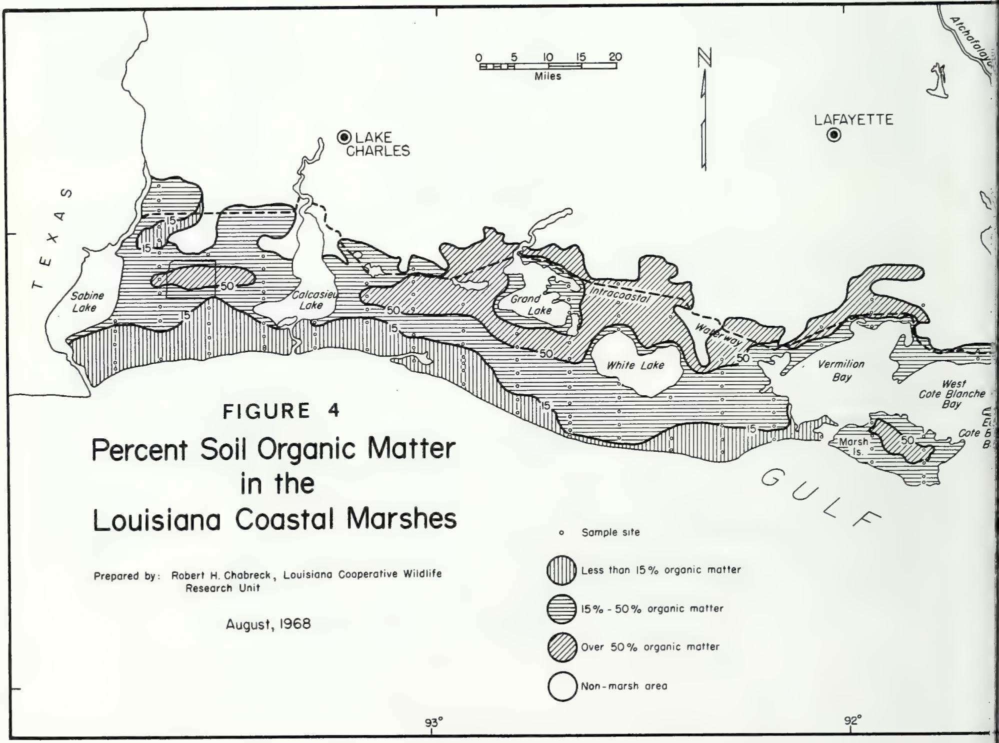


FIGURE 4

Percent Soil Organic Matter in the Louisiana Coastal Marshes

Prepared by: Robert H. Chabreck, Louisiana Cooperative Wildlife Research Unit

August, 1968

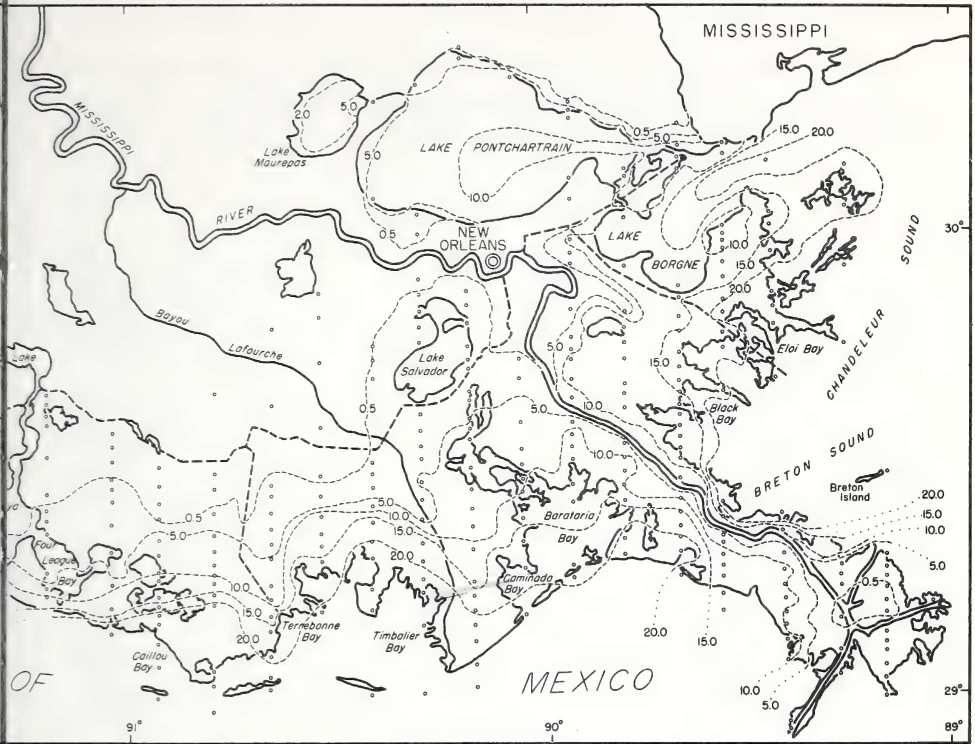
∘ Sample site

▥ Less than 15% organic matter

▤ 15% - 50% organic matter

▨ Over 50% organic matter

○ Non-marsh area


MISSISSIPPI
MISSISSIPPI
RIVER
Lake Maurepas
2.0
5.0
LAKE PONTCHARTRAIN
5.0
10.0
0.5
0.5
5.0
15.0
20.0
NEW ORLEANS
LAKE
BORGNE
10.0
15.0
20.0
SOUND
CHANDELEUR
Eloi Bay
Black Bay
BRETON SOUND
Breton Island
20.0
15.0
10.0
5.0
Bayou
Lafourche
Lake
Lake Salvador
5.0
15.0
0.5
5.0
10.0
10.0
5.0
10.0
15.0
20.0
0.5
5.0
Four League Bay
10.0
15.0
20.0
Barataria Bay
Caminada Bay
Terrebonne Bay
Timbalier Bay
Caillou Bay
20.0
15.0
0.5
10.0
5.0
OF
MEXICO
30°
29°
91°
90°
89°

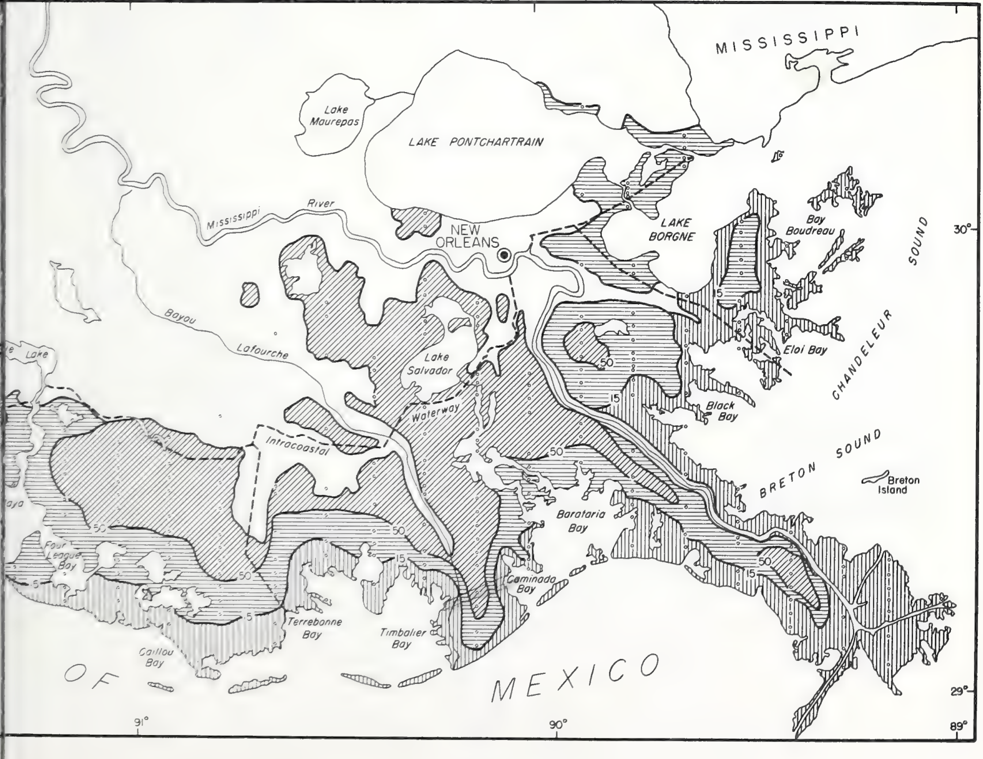

MISSISSIPPI
Lake Maurepas
LAKE PONTCHARTRAIN
Mississippi
River
NEW ORLEANS
LAKE
BORGNE
Bay
Boudreau
SOUND
CHANDELEUR
15
Eloi Bay
Bayou
Lafourche
Lake
Lake Salvador
Waterway
Intracoastal
50
15
Black Bay
BRETON SOUND
Breton Island
50
50
50
15
Four League Bay
50
15
5
Barataria Bay
Caminada Bay
Terrebonne Bay
Timbalier Bay
Caillou Bay
50
15
OF
MEXICO
30°
29°
91°
90°
89°

Table 11. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	------------------- Percent	-------------------	-------------------	-------------------
	Hydrologic Unit 8 (Continued)			
Lycium carolinianum	1.56	- -	- -	- -
Nelumbo lutea	- -	- -	- -	1.32
Nymphaea odorata	- -	- -	- -	2.41
Panicum hemitomon	- -	- -	- -	21.50
Paspalum dissectum	- -	- -	- -	1.40
Paspalum vaginatum	- -	1.84	6.39	- -
Phragmites communis	- -	- -	5.96	- -
Pluchea camphorata	- -	- -	2.47	- -
Potamogeton pusillus	- -	- -	- -	1.01
Sagittaria falcata	- -	- -	2.55	28.00
Salicornia bigelovii	1.56	- -	- -	- -
Scirpus americanus	- -	- -	4.68	- -
Scirpus robustus	6.25	4.19	- -	- -
Sesuvium portulacastrum	- -	- -	2.98	- -
Spartina alterniflora	10.94	- -	- -	- -
Spartina cynosuroides	- -	2.08	- -	- -
Spartina patens	6.25	53.80	36.84	8.09
Spartina spartineae	- -	- -	1.28	- -
Utricularia cornuta	- -	- -	- -	3.42
Vigna repens	- -	- -	1.49	- -
Other species[b]	- -	5.15	5.33	10.43
	Hydrologic Unit 9			
Acnida alabamensis	- -	- -	1.21	- -
Alternanthera philoxeroides	- -	- -	2.24	25.87
Bacopa monnieri	- -	5.33	2.49	2.99
Batis maritima	20.24	- -	- -	- -
Cynodon dactylon	- -	- -	- -	2.99
Daubentonia texana	- -	- -	- -	1.29
Distichlis spicata	54.66	8.96	- -	1.99
Echinochloa walteri	- -	- -	- -	2.19
Eleocharis sp.	- -	- -	- -	8.46
Juncus effusus	- -	- -	- -	1.99
Leptochloa fascicularis	- -	- -	3.00	- -
Numphaea odorata	- -	- -	- -	1.99
Panicum hemitomon	- -	- -	- -	1.99
Paspalum vaginatum	- -	7.22	13.29	5.77
Ruppia maritima	- -	1.18	- -	- -
Phragmites communis	- -	- -	3.97	- -
Sagittaria falcata	- -	- -	4.59	22.88
Scirpus californicus	- -	- -	6.73	4.98
Scirpus olneyi	- -	6.99	6.21	- -
Scirpus robustus	- -	2.49	1.21	- -
Sesbania exaltata	- -	- -	2.07	- -
Setaria glauca	- -	1.38	- -	- -
Spartina alterniflora	24.29	- -	- -	- -

(Continued)

Table 11. (Continued)

Species	Vegetative Type			
	Saline	Brackish	Intermediate	Fresh
	Percent			
Hydrologic Unit 9 (Continued)				
Spartina patens	- -	59.81	46.83	7.96
Spartina spartineae	- -	1.58	1.73	- -
Utricularia cornuta	- -	- -	- -	3.98
Other species[b]	.81	5.06	4.43	2.68

[a] Includes only natural marshes.

[b] Includes only plants making up less than 1.00 percent of the species composition.

Table 12. Plant coverage of ponds and lakes by vegetative type along the Louisiana coast

Lake Size Class (Acres)	Vegetative Type				
	Saline	Brackish	Intermediate	Fresh	Entire Coast
	Percent				
<.01 -	0	8.6	11.4	53.2	20.0
.01 - .10	0	15.4	29.1	75.6	35.4
.10 - 1.0	0	8.1	37.7	71.7	31.1
1.0 - 10	0	10.7	19.5	56.4	23.9
10 - 80	0	16.3	13.1	28.4	16.0
80 - 640	0	7.1	0	29.6	15.1
640 - 3,200	0	7.9	0	4.0	3.8
3,200 - 16,000	0	0	0	0	0
16,000 - 64,000	0	0	0	0	0
>64,000	0	0	0	0	0

Table 13. Plant species composition of ponds and lakes by vegetative type along the Louisiana coast

Plant Species	Vegetative Type[a]			
	Brackish	Intermediate	Fresh	Entire Coast
	Percent			
Alternanthera philoxeroides	- -	- -	1.29	.89
Azolla caroliniana	- -	- -	.59	.40
Bacopa caroliniana	- -	- -	.35	.24
Bacopa monnieri	4.97	11.69	.35	2.46
Bacopa rotundifolia	2.29	- -	- -	.49
Brasenia schreberi	- -	- -	2.23	1.54
Cabomba caroliniana	- -	- -	3.64	2.51
Centella erecta	- -	- -	.63	.44
Ceratophyllum demersum	- -	- -	11.15	7.68
Chara vulgaris	- -	32.47	8.10	8.81
Eichornia crassipes	- -	- -	4.53	3.12
Eleocharis parvula	23.01	10.07	1.60	6.97
Eleocharis sp.	3.98	6.82	11.27	9.28
Hydrocotyl bonariensis	- -	- -	.12	.08
Hydrocotyl umbellata	- -	- -	1.67	1.15
Hymenocallis occidentalis	- -	- -	.47	.32
Jussiaea sp.	- -	- -	.23	.16
Lemna minor	- -	2.43	15.26	10.75
Limnobium spongia	- -	- -	1.13	.78
Myriophyllum spicatum	3.06	8.93	11.03	9.14
Myriophyllum heterophyllum	- -	- -	.47	.32
Najas quadalupensis	- -	8.93	5.75	4.85
Nelumbo lutea	- -	- -	1.88	1.29
Nymphaea odorata	- -	- -	4.93	3.40
Potamogeton nodosus	- -	- -	.23	.16
Potamogeton pusillus	- -	4.87	2.70	2.34
Ruppia maritima	62.69	12.98	.23	14.72
Sagittaria falcata	- -	- -	1.24	.86
Scirpus californicus	- -	.81	- -	.08
Spirodela polyrhiza	- -	- -	.94	.65
Utricularia cornuta	- -	- -	5.99	4.12

[a] No vegetation in saline vegetative type.

Table 14. Plant species composition of ponds and lakes of various size classes along the Louisiana coast

Plant species	Pond Size Classes[a]				
	<.01	.01-.10	.10-1.0	1.0-10	10-80
	Percent				
Alternanthera philoxeroides	- -	- -	- -	- -	1.01
Azolla caroliniana	- -	.52	- -	1.69	- -
Bacopa caroliniana	- -	- -	- -	1.26	- -
Bacopa monnieri	- -	12.67	- -	.85	2.02
Bacopa rotundifolia	- -	- -	- -	2.53	- -
Brasenia schreberi	- -	- -	1.92	5.49	- -
Cabomba caroliniana	- -	1.04	.32	5.07	8.06
Centella erecta	8.33	- -	- -	.85	- -
Ceratophyllum demersum	- -	3.63	2.88	4.22	2.02
Chara vulgaris	- -	1.04	20.50	9.71	10.08
Eichornia crassipes	24.51	- -	6.28	2.11	- -
Eleocharis parvula	40.20	10.70	4.68	5.32	3.53

(Continued)

Table 14. (Continued)

	Pond Size Classes[a]				
Plant Species	<.01	.01-.10	.10-1.0	1.0-10	10-80
	Percent				
Eleocharis sp.	22.06	26.17	14.41	2.95	.20
Hydrocotyl bonariensis	- -	.52	- -	- -	- -
Hydrocotyl umbellata	- -	4.46	1.15	.85	- -
Hymenocallis occidentalis	- -	2.08	- -	- -	- -
Jussiaea sp.	- -	- -	.64	- -	- -
Lemna minor	- -	9.35	11.34	12.92	5.54
Limnobium spongia	- -	4.67	- -	.25	- -
Myriophyllum spicatum	- -	- -	3.20	- -	26.21
Myriophyllum heterophyllum	- -	- -	- -	1.69	- -
Najas quadalupensis	- -	1.04	5.13	15.20	3.02
Nelumbo lutea	- -	- -	1.28	- -	1.01
Nymphaea odorata	- -	1.04	5.13	5.07	4.03
Potamogeton nodosus	- -	- -	- -	.85	- -
Potamogeton pusillus	- -	- -	1.60	5.49	1.01
Ruppia maritima	- -	6.75	10.89	11.40	32.26
Sagittaria falcata	- -	3.42	.64	- -	- -
Scirpus californicus	- -	- -	.32	- -	- -
Spirodela polyrhiza	- -	2.59	- -	.85	- -
Utricularia cornuta	4.90	8.31	7.69	3.38	- -

	Pond Size Classes[a]				
Plant Species	80-640	640-3,200	3,200-16,000	16,000-64,000	>64,000
	Percent				
Alternanthera philoxeroides	3.84	2.70	- -	- -	- -
Azolla caroliniana	- -	- -	- -	- -	- -
Bacopa caroliniana	- -	- -	- -	- -	- -
Bacopa monnieri	- -	- - -	- -	- -	- -
Brasenia schreberi	- -	- -	- -	- -	- -
Cabomba caroliniana	- -	- -	- -	- -	- -
Centella erecta	- -	- -	- -	- -	- -
Ceratophyllum demersum	21.43	35.14	- -	- -	- -
Chara vulgaris	- -	5.41	- -	- -	- -
Eichornia crassipes	- -	- -	- -	- -	- -
Eleocharis parvula	8.24	- -	- -	- -	- -
Eleocharis sp.	1.65	- -	- -	- -	- -
Hydrocotyl bonariensis	- -	- -	- -	- -	- -
Hydrocotyl umbellata	- -	- -	- -	- -	- -
Hymenocallis occidentalis	- -	- -	- -	- -	- -
Jussiaea sp.	- -	- -	- -	- -	- -
Lemna minor	20.88	- -	- -	- -	- -
Limnobium spongia	- -	- -	- -	- -	- -
Myriophyllum spicatum	26.92	2.70	- -	- -	- -
Myriophyllum heterophyllum	- -	- -	- -	- -	- -
Najas quadalupensis	- -	- -	- -	- -	- -
Nelumbo lutea	5.49	- -	- -	- -	- -
Nymphaea odorata	2.20	- -	- -	- -	- -
Potamogeton nodosus	- -	- -	- -	- -	- -
Potamogeton pusillus	4.95	- -	- -	- -	- -
Ruppia maritima	2.20	54.05	- -	- -	- -
Sagittaria falcata	1.10	- -	- -	- -	- -
Scirpus californicus	- -	- -	- -	- -	- -
Spirodela polyrhiza	.55	- -	- -	- -	- -
Utricularia cornuta	.55	- -	- -	- -	- -

[a] Pond size in acres

Table 15. Mean values of soil and water chemical characteristics for major species of marsh vegetation

			DRY WEIGHT BASIS				WET WEIGHT BASIS					
Plant Species	pH Range	Water Salinity (ppt)	Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Acnida alabamensis	4.10-7.50 (32)*	7.29±5.22** (31)	1.36±0.74 (32)	22.36±13.07 (32)	38.48±22.54 (32)	15.98±3.26 (32)	0.03±0.03 (32)	0.21±0.15 (32)	0.37±0.37 (32)	0.97±0.56 (32)	2.72±1.46 (32)	6.44±3.95 (32)
Alternanthera philoxeroides	4.80-7.70 (33)	2.73±4.94 (30)	1.26±0.89 (33)	19.00±15.54 (33)	32.72±26.51 (33)	14.09±3.90 (33)	0.04±0.05 (33)	0.11±0.11 (33)	0.85±0.73 (33)	0.64±0.41 (33)	0.85±1.14 (33)	2.37±3.39 (33)
Ammannia coccinea	4.00-5.90 (3)	5.72±3.55 (3)	2.22±0.76 (3)	36.07±8.73 (3)	62.18±15.06 (3)	16.71±2.40 (3)	0.01±0.00 (3)	0.10±0.06 (3)	0.23±0.18 (3)	0.63±0.25 (3)	2.14±0.91 (3)	6.12±4.90 (3)
Aster sp.	4.50-7.50 (17)	9.69±6.24 (15)	1.16±0.88 (17)	17.50±14.72 (17)	30.16±25.38 (17)	15.28±6.12 (17)	0.04±0.05 (17)	0.23±0.14 (17)	0.60±0.60 (17)	0.88±0.30 (17)	2.79±1.11 (17)	6.26±3.51 (17)
Avicennia nitida	5.70-7.70 (8)	25.72±13.65 (6)	0.31±0.16 (8)	4.72±2.82 (8)	8.12±4.89 (8)	14.86±2.44 (8)	0.12±0.04 (8)	0.39±0.16 (8)	0.61±0.80 (8)	1.09±0.41 (8)	5.18±2.87 (8)	11.94±6.07 (8)
Baccharis halimifolia	4.00-7.50 (38)	7.46±5.57 (31)	1.06±0.84 (38)	16.63±13.83 (38)	28.67±23.83 (38)	15.94±3.28 (38)	0.06±0.07 (38)	0.20±0.12 (38)	0.74±0.89 (38)	0.94±0.47 (38)	2.25±1.66 (38)	5.81±4.84 (38)
Bacopa caroliniana	5.10-5.90 (8)	2.83±4.41 (6)	1.79±1.17 (8)	27.41±18.83 (8)	50.27±28.78 (8)	15.00±2.16 (8)	0.01±0.01 (8)	0.05±0.04 (8)	0.41±0.22 (8)	0.42±0.27 (8)	0.73±1.00 (8)	1.91±2.24 (8)
Bacopa monnieri	4.00-7.50 (31)	3.93±2.27 (29)	1.76±0.89 (31)	28.41±14.90 (31)	48.99±25.66 (31)	16.14±3.05 (31)	0.02±0.03 (31)	0.12±0.09 (31)	0.55±0.68 (31)	0.90±0.67 (31)	1.87±0.86 (31)	4.60±2.65 (31)
Batis maritima	4.00-7.90 (16)	23.60±9.97 (13)	0.23±0.14 (16)	4.33±3.30 (16)	7.47±5.69 (16)	17.92±7.23 (16)	0.11±0.06 (16)	0.33±0.15 (16)	0.54±0.84 (16)	1.22±0.73 (16)	6.45±9.22 (16)	10.55±6.38 (16)
Bidens laevis	4.70-5.40 (5)	0.81±0.61 (4)	2.52±0.89 (5)	38.58±15.03 (5)	66.51±25.91 (5)	15.34±3.16 (5)	0.01±0.00 (5)	0.03±0.03 (5)	0.83±0.71 (5)	0.23±0.16 (5)	0.26±0.21 (5)	1.05±0.59 (5)
Borrichia frutescens	6.10-7.50 (6)	12.24±8.52 (5)	0.42±0.16 (6)	5.41±2.83 (6)	9.30±4.91 (6)	12.73±2.34 (6)	0.10±0.03 (6)	0.44±0.07 (6)	0.48±0.39 (6)	1.19±0.36 (6)	3.64±1.21 (6)	8.96±4.72 (6)
Carex sp.	5.00-7.50 (3)	0.09±0.00 (1)	1.25±1.66 (3)	18.32±23.13 (3)	31.58±41.59 (3)	16.26±5.83 (3)	0.08±0.09 (3)	0.17±0.17 (3)	1.94±1.61 (3)	1.16±1.07 (3)	1.41±2.07 (3)	3.44±5.62 (3)
Centella erecta	4.50-5.30 (4)	2.18±1.37 (3)	1.40±0.48 (4)	29.21±15.44 (4)	50.35±26.62 (4)	20.36±5.47 (4)	0.01±0.01 (4)	0.08±0.04 (4)	0.50±0.44 (4)	0.61±0.13 (4)	0.77±0.48 (4)	3.10±2.97 (4)
Cephalanthus occidentalis	4.90-6.20 (14)	0.72±1.00 (13)	1.80±0.97 (14)	31.15±17.83 (14)	53.76±30.77 (14)	16.56±3.43 (14)	0.01±0.01 (14)	0.04±0.03 (14)	0.09±0.14 (14)	0.30±0.25 (14)	0.28±0.29 (14)	0.79±0.90 (14)
Chara vulgaris	5.20-6.20 (8)	1.85±2.00 (8)	1.47±0.99 (8)	23.01±16.97 (8)	39.67±29.26 (8)	14.79±2.75 (8)	0.01±0.00 (8)	0.08±0.07 (8)	0.42±0.23 (8)	0.70±0.35 (8)	0.95±0.73 (8)	1.97±1.42 (8)

(continued)

Plant Species	pH Range	Water Salinity (ppt)	DRY WEIGHT BASIS				WET WEIGHT BASIS					
			Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Cladium jamaicense	4.50-7.50 (8)	3.96±2.58 (5)	1.80±0.97 (8)	28.51±17.72 (8)	49.25±30.61 (8)	17.65±6.38 (8)	0.03±0.06 (8)	0.09±0.11 (8)	0.91±0.86 (8)	0.84±0.67 (8)	1.47±1.23 (8)	3.48±3.01 (8)
Colocasia antiquorum	5.40-6.40 (3)	0.64±0.39 (3)	0.80±0.63 (3)	10.26±7.35 (3)	17.68±12.67 (3)	13.24±1.02 (3)	0.05±0.05 (3)	0.10±0.03 (3)	0.71±0.46 (3)	0.56±0.28 (3)	0.24±0.10 (3)	0.49±0.14 (3)
Cuscuta indecora	4.50-6.10 (6)	6.23±2.86 (6)	1.41±0.93 (6)	17.11±12.67 (6)	29.50±21.85 (6)	14.02±5.57 (6)	0.03±0.03 (6)	0.17±0.10 (6)	0.66±0.26 (6)	0.86±0.19 (6)	2.39±0.29 (6)	5.65±1.09 (6)
Cyperus compressus	5.20-7.50 (3)	0.16±0.05 (2)	1.79±1.50 (3)	31.79±26.82 (3)	54.78±46.28 (3)	15.74±4.02 (3)	0.01±0.01 (3)	0.06±0.09 (3)	3.47±3.79 (3)	0.22±0.17 (3)	0.84±1.35 (3)	0.99±1.55 (3)
Cyperus odoratus	3.80-7.50 (66)	3.20±2.80 (61)	1.52±0.98 (66)	24.58±16.62 (66)	42.04±28.94 (66)	15.64±3.82 (66)	0.03±0.05 (66)	0.13±0.10 (66)	0.38±0.29 (66)	0.78±0.46 (66)	1.45±0.98 (66)	3.53±2.72 (66)
Daubentonia texana	4.30-8.00 (27)	2.61±4.32 (24)	0.84±0.73 (27)	12.48±12.60 (27)	21.51±21.72 (27)	14.60±3.54 (27)	0.05±0.06 (27)	0.14±0.11 (27)	0.65±0.39 (27)	0.90±0.50 (27)	0.95±0.85 (27)	1.99±2.03 (27)
Decodon verticillatus	4.30-5.30 (8)	1.23±1.41 (8)	2.43±0.64 (8)	43.02±11.29 (8)	74.17±19.46 (8)	17.81±1.93 (8)	0.01±0.00 (8)	0.03±0.03 (8)	0.33±0.22 (8)	0.23±0.23 (8)	0.55±0.78 (8)	1.94±2.97 (8)
Dichromenia colorata	5.20-5.80 (4)	2.39±2.17 (3)	2.36±0.81 (4)	42.28±9.35 (4)	72.90±16.12 (4)	18.85±3.65 (4)	0.01±0.00 (4)	0.03±0.03 (4)	0.59±0.12 (4)	0.40±0.29 (4)	0.79±0.78 (4)	1.82±1.91 (4)
Distichlis spicata	4.10-8.00 (94)	13.32±6.70 (80)	0.77±0.61 (94)	13.03±10.61 (94)	22.46±18.29 (94)	16.92±4.42 (94)	0.06±0.05 (94)	0.29±0.12 (94)	0.32±0.39 (94)	1.05±0.41 (94)	4.12±3.92 (94)	8.81±4.03 (94)
Dryopteris thelypteris	4.30-5.60 (5)	0.67±0.43 (5)	1.89±0.91 (5)	31.46±17.53 (5)	54.24±30.23 (5)	15.91±2.31 (5)	0.01±0.01 (5)	0.06±0.04 (5)	0.41±0.21 (5)	0.35±0.23 (5)	0.30±0.25 (5)	1.46±1.11 (5)
Echinochloa walteri	3.80-7.40 (46)	2.89±2.43 (44)	1.60±0.94 (46)	25.65±16.41 (46)	44.31±28.15 (46)	14.97±3.96 (46)	0.02±0.03 (46)	0.10±0.09 (46)	0.39±0.27 (46)	0.80±0.58 (46)	1.21±0.69 (46)	2.80±1.92 (46)
Eichornia crassipes	4.50-6.90 (7)	0.37±0.10 (4)	1.10±0.78 (7)	15.44±12.55 (7)	26.59±21.67 (7)	13.61±2.29 (7)	0.03±0.04 (7)	0.07±0.04 (7)	0.55±0.20 (7)	0.56±0.37 (7)	0.23±0.10 (7)	0.68±0.44 (7)
Eleocharis parvula	3.70-6.70 (29)	6.69±3.84 (29)	1.53±0.73 (29)	26.26±13.65 (29)	45.27±23.53 (29)	16.91±4.98 (29)	0.02±0.02 (29)	0.15±0.09 (29)	0.25±0.21 (29)	0.81±0.42 (29)	2.40±1.30 (29)	6.00±3.47 (29)
Eleocharis sp.	4.00-8.00 (69)	3.88±4.29 (66)	1.99±0.87 (69)	33.62±15.11 (69)	58.30±25.47 (69)	17.00±3.33 (69)	0.01±0.02 (69)	0.08±0.08 (69)	0.47±0.31 (69)	0.50±0.35 (69)	1.31±1.24 (69)	3.38±3.24 (69)
Eupatorium capillifolium	4.30-5.80 (9)	1.26±1.37 (7)	2.06±1.12 (9)	33.48±18.67 (9)	57.76±32.21 (9)	15.75±1.63 (9)	0.01±0.02 (9)	0.06±0.07 (9)	0.68±0.44 (9)	0.36±0.32 (9)	0.70±0.77 (9)	1.86±2.00 (9)

(continued)

Table 15. (Continued)

			DRY WEIGHT BASIS				WET WEIGHT BASIS					
Plant Species	pH Range	Water Salinity (ppt)	Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Eupatorium sp.	4.00-7.10 (8)	4.51±7.13 (6)	2.12±1.19 (8)	35.99±19.85 (8)	62.05±34.22 (8)	17.71±2.16 (8)	0.04±0.08 (8)	0.10±0.13 (8)	0.91±0.60 (8)	0.48±0.42 (8)	0.93±1.43 (8)	2.38±3.68 (8)
Fimbristylis castanea	5.40-7.80 (8)	9.85±7.05 (4)	0.89±0.95 (8)	15.61±17.28 (8)	29.92±28.34 (8)	16.78±5.06 (8)	0.02±0.02 (8)	0.15±0.06 (8)	0.27±0.17 (8)	0.78±0.43 (8)	2.24±1.51 (8)	5.04±4.47 (8)
Gerardia maritima	5.20-6.90 (4)	7.01±3.00 (3)	1.61±1.11 (4)	28.51±20.32 (4)	49.15±35.03 (4)	15.89±4.00 (4)	0.03±0.05 (4)	0.14±0.08 (4)	0.30±0.18 (4)	0.67±0.21 (4)	2.01±0.45 (4)	4.89±1.71 (4)
Hibiscus lasiocarpus	4.30-7.50 (8)	1.38±1.24 (6)	1.39±1.04 (8)	22.45±18.19 (8)	38.71±31.36 (8)	15.90±3.58 (8)	0.03±0.06 (8)	0.12±0.11 (8)	0.79±0.89 (8)	0.68±0.68 (8)	0.98±1.21 (8)	3.63±4.20 (8)
Hydrocotyl sp.	4.30-6.90 (31)	1.22±1.16 (27)	2.38±0.83 (31)	39.87±14.50 (31)	69.51±23.24 (31)	16.68±2.09 (31)	0.01±0.03 (31)	0.03±0.04 (31)	0.46±0.23 (31)	0.29±0.26 (31)	0.49±0.52 (31)	1.30±1.21 (31)
Hymenocallis occidentalis	5.40-6.80 (3)	3.69±4.91 (3)	0.82±0.50 (3)	10.42±7.77 (3)	17.89±13.43 (3)	12.24±1.79 (3)	0.03±0.04 (3)	0.21±0.23 (3)	0.68±0.38 (3)	0.95±0.54 (3)	1.74±2.15 (3)	5.85±8.35 (3)
Hypericum virginicum	5.00-5.90 (5)	0.71±1.12 (5)	2.80±0.35 (5)	45.29±4.84 (5)	78.07±8.34 (5)	16.30±1.85 (5)	0.00±0.00 (5)	0.02±0.01 (5)	0.50±0.14 (5)	0.15±0.14 (5)	0.32±0.53 (5)	1.13±1.37 (5)
Iva ciliata	5.60-7.50 (4)	1.61±1.51 (3)	0.49±0.25 (4)	5.70±2.74 (4)	15.85±8.65 (4)	12.45±3.10 (4)	0.06±0.05 (4)	0.19±0.18 (4)	1.44±0.82 (4)	1.03±0.63 (4)	0.83±0.77 (4)	1.40±0.60 (4)
Iva frutescens	4.00-7.20 (38)	10.29±8.02 (35)	0.94±0.66 (38)	15.59±11.70 (38)	26.88±20.18 (38)	16.43±2.93 (38)	0.05±0.05 (38)	0.23±0.12 (38)	0.34±0.24 (38)	0.93±0.31 (38)	3.18±1.79 (38)	7.73±5.06 (38)
Ipomoea sagittata	3.80-7.50 (27)	4.91±4.71 (23)	1.30±0.83 (27)	20.69±14.75 (27)	36.56±24.69 (27)	15.77±4.20 (27)	0.02±0.03 (27)	0.12±0.08 (27)	0.50±0.39 (27)	0.83±0.46 (27)	1.81±1.29 (27)	4.83±3.53 (27)
Juncus effusus	5.30-5.90 (3)	0.23±0.01 (2)	0.61±0.43 (3)	7.22±4.37 (3)	20.49±6.90 (3)	13.20±3.08 (3)	0.03±0.03 (3)	0.10±0.04 (3)	2.41±2.73 (3)	0.58±0.21 (3)	0.15±0.07 (3)	0.79±0.59 (3)
Juncus roemerianus	4.30-7.10 (70)	13.89±8.27 (63)	0.84±0.61 (70)	15.18±11.27 (70)	26.17±19.44 (70)	18.11±4.80 (70)	0.05±0.05 (70)	0.26±0.12 (70)	0.40±0.53 (70)	0.95±0.30 (70)	3.59±1.77 (70)	9.20±4.33 (70)
Jussiaea diffusa	5.00-5.70 (7)	0.38±0.35 (7)	2.06±0.96 (7)	34.93±17.25 (7)	60.14±29.77 (7)	16.34±3.10 (7)	0.01±0.00 (7)	0.04±0.03 (7)	0.62±0.28 (7)	0.31±0.36 (7)	0.22±0.23 (7)	0.52±0.55 (7)
Jussiaea sp.	4.90-5.80 (6)	1.12±0.87 (6)	1.84±0.79 (6)	30.72±12.95 (6)	52.93±22.35 (6)	16.82±3.91 (6)	0.01±0.00 (6)	0.05±0.03 (6)	0.52±0.18 (6)	0.48±0.25 (6)	0.61±0.45 (6)	1.31±1.09 (6)
Kosteletzyka virginica	4.40-7.50 (12)	2.55±1.02 (10)	1.77±0.92 (12)	29.85±14.81 (12)	51.04±25.47 (12)	17.58±2.97 (12)	0.02±0.05 (12)	0.10±0.10 (12)	0.74±0.52 (12)	0.65±0.57 (12)	1.60±1.18 (12)	3.72±3.04 (12)

(continued)

Table 15. (Continued)

			DRY WEIGHT BASIS				WET WEIGHT BASIS					
Plant Species	pH Range	Water Salinity (ppt)	Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Lemna minor	4.10-7.10 (16)	1.13±0.76 (13)	2.04±1.06 (16)	32.09±16.88 (16)	55.31±29.11 (16)	15.49±3.01 (16)	0.04±0.07 (16)	0.05±0.05 (16)	0.36±0.19 (16)	0.42±0.37 (16)	0.42±0.31 (16)	1.37±1.14 (16)
Leptochloa fascicularis	4.60-7.50 (10)	5.05±3.17 (9)	1.91±1.08 (10)	30.62±18.26 (10)	52.78±31.48 (10)	15.15±3.27 (10)	0.02±0.02 (10)	0.13±0.09 (10)	0.38±0.18 (10)	0.98±0.84 (10)	2.18±0.73 (10)	4.84±2.73 (10)
Limnobium spongia	5.10-5.90 (4)	0.45±0.39 (4)	1.68±1.07 (4)	27.89±20.02 (4)	48.09±34.52 (4)	14.99±3.81 (4)	0.01±0.00 (4)	0.04±0.03 (4)	0.50±0.15 (4)	0.35±0.51 (4)	0.47±0.59 (4)	1.95±0.88 (4)
Lippia nodiflora	4.30-5.90 (6)	1.88±0.76 (5)	2.45±0.66 (6)	39.03±12.21 (6)	67.29±21.05 (6)	15.72±1.85 (6)	0.01±0.00 (6)	0.04±0.02 (6)	0.49±0.09 (6)	0.32±0.19 (6)	0.80±0.34 (6)	1.97±0.60 (6)
Lythrum lineare	3.70-6.50 (23)	5.45±4.02 (23)	1.79±0.91 (23)	29.92±15.61 (23)	51.57±26.90 (23)	16.87±5.24 (23)	0.02±0.03 (23)	0.13±0.10 (23)	0.33±0.21 (23)	0.78±0.61 (23)	2.10±1.02 (23)	4.88±2.57 (23)
Myrica cerifera	4.30-5.60 (16)	1.29±1.13 (14)	2.23±0.84 (16)	39.41±13.93 (16)	67.98±24.00 (16)	17.86±3.35 (16)	0.01±0.01 (16)	0.03±0.02 (16)	0.40±0.19 (16)	0.25±0.12 (16)	0.40±0.30 (16)	1.20±0.89 (16)
Najas quadalupensis	5.00-6.20 (7)	0.64±0.41 (7)	1.32±1.15 (7)	17.91±16.67 (7)	30.87±28.73 (7)	13.28±1.42 (7)	0.01±0.01 (7)	0.09±0.05 (7)	0.48±0.18 (7)	0.93±0.43 (7)	0.66±0.43 (7)	1.23±1.09 (7)
Nymphaea odorata	5.00-5.40 (5)	0.36±0.23 (5)	1.74±1.20 (5)	28.29±20.12 (5)	48.77±34.68 (5)	15.26±2.51 (5)	0.01±0.00 (5)	0.04±0.02 (5)	0.37±0.15 (5)	0.43±0.18 (5)	0.30±0.26 (5)	0.66±0.70 (5)
Osmunda regalis	4.30-5.20 (6)	1.45±1.31 (6)	2.65±0.48 (6)	45.75±4.91 (6)	79.02±8.15 (6)	17.52±1.79 (6)	0.01±0.00 (6)	0.04±0.03 (6)	0.38±0.24 (6)	0.25±0.05 (6)	0.46±0.05 (6)	1.35±0.84 (6)
Panicum hemitomon	4.30-6.30 (50)	1.02±1.13 (43)	2.10±0.88 (50)	35.18±15.55 (50)	61.03±26.00 (50)	16.38±2.60 (50)	0.01±0.01 (50)	0.04±0.03 (50)	0.48±0.24 (50)	0.29±0.24 (50)	0.38±0.36 (50)	1.08±0.88 (50)
Panicum repens	5.50-8.00 (7)	1.73±1.22 (6)	0.27±0.23 (7)	3.69±2.47 (7)	6.36±4.26 (7)	15.67±4.15 (7)	0.14±0.06 (7)	0.19±0.09 (7)	1.45±0.81 (7)	1.06±0.28 (7)	0.83±0.57 (7)	1.86±1.17 (7)
Panicum virgatum	4.50-7.50 (17)	3.14±3.68 (15)	1.31±0.86 (17)	22.60±14.73 (17)	38.95±25.39 (17)	17.60±3.58 (17)	0.03±0.05 (17)	0.13±0.10 (17)	0.77±0.43 (17)	0.80±0.52 (17)	1.40±1.46 (17)	3.91±4.07 (17)
Paspalam vaginatum	5.10-6.70 (17)	3.27±3.47 (16)	0.73±0.34 (17)	10.18±7.76 (17)	17.80±13.09 (17)	12.88±4.49 (17)	0.04±0.03 (17)	0.25±0.12 (17)	0.65±0.43 (17)	1.28±0.38 (17)	1.80±1.21 (17)	3.40±2.88 (17)
Phragmites communis	3.70-8.00 (35)	3.33±3.96 (29)	0.82±0.77 (35)	14.05±15.03 (35)	24.22±25.92 (35)	15.89±4.59 (35)	0.06±0.07 (35)	0.18±0.12 (35)	0.64±0.60 (35)	0.97±0.50 (35)	1.43±1.38 (35)	3.62±3.68 (35)

(continued)

Table 15. (Continued)

Plant Species	pH Range	Water Salinity (ppt)	DRY WEIGHT BASIS				WET WEIGHT BASIS					
			Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Pluchaea camphorata	3.80-8.00 (50)	6.34±5.53 (47)	1.55±0.91 (50)	25.46±15.03 (50)	43.80±25.87 (50)	16.39±4.06 (50)	0.03±0.04 (50)	0.14±0.11 (50)	0.32±0.25 (50)	0.79±0.42 (50)	2.08±1.05 (50)	5.18±3.14 (50)
Polygonum sp.	4.00-5.60 (15)	2.12±2.07 (12)	2.01±1.01 (15)	32.00±17.44 (15)	55.18±30.06 (15)	15.33±2.59 (15)	0.01±0.02 (15)	0.06±0.05 (15)	0.42±0.24 (15)	0.38±0.29 (15)	0.84±0.70 (15)	2.34±1.79 (15)
Rhynchospora corniculata	5.10-5.60 (3)	0.28±0.06 (2)	1.31±0.79 (3)	20.95±16.91 (3)	36.11±29.15 (3)	14.72±3.20 (3)	0.02±0.03 (3)	0.07±0.05 (3)	0.61±0.03 (3)	0.43±0.31 (3)	0.14±0.05 (3)	1.62±1.22 (3)
Ruppia maritima	3.70-6.40 (26)	8.95±6.39 (26)	0.92±0.55 (26)	15.59±11.60 (26)	26.89±19.99 (26)	16.12±3.92 (26)	0.04±0.03 (26)	0.25±0.14 (26)	0.35±0.29 (26)	1.06±0.40 (26)	4.40±7.24 (26)	7.02±3.15 (26)
Sagittaria falcata	4.30-6.30 (71)	1.70±1.59 (64)	1.78±0.93 (71)	28.78±16.19 (71)	49.55±27.92 (71)	15.69±3.01 (71)	0.01±0.02 (71)	0.06±0.06 (71)	0.46±0.29 (71)	0.55±0.48 (71)	0.73±0.52 (71)	1.79±1.49 (71)
Salicornia bigelovii	6.60-8.50 (5)	14.84±16.79 (2)	0.06±0.09 (5)	0.90±1.14 (5)	1.52±1.90 (5)	16.76±10.50 (5)	0.11±0.02 (5)	0.22±0.19 (5)	0.74±0.76 (5)	1.24±1.19 (5)	2.24±1.46 (5)	4.96±3.48 (5)
Salix nigra	4.70-7.50 (28)	0.93±0.05 (23)	1.80±0.95 (28)	29.34±16.22 (28)	50.58±27.96 (28)	16.15±3.13 (28)	0.02±0.04 (28)	0.06±0.07 (28)	0.64±0.30 (28)	0.47±0.47 (28)	0.51±0.73 (28)	1.40±1.84 (28)
Saururus cernuus	5.10-6.40 (3)	0.32±0.05 (3)	1.71±1.27 (3)	31.07±24.32 (3)	53.56±41.93 (3)	16.78±2.88 (3)	0.04±0.06 (3)	0.04±0.05 (3)	0.45±0.15 (3)	0.36±0.44 (3)	0.18±0.08 (3)	1.38±1.35 (3)
Scirpus americanus	6.70-7.80 (5)	1.50±1.15 (4)	0.19±0.16 (5)	2.69±2.30 (5)	4.64±3.97 (5)	15.35±4.47 (5)	0.14±0.08 (5)	0.17±0.09 (5)	1.38±0.51 (5)	0.91±0.38 (5)	0.72±0.28 (5)	1.63±0.62 (5)
Scirpus californicus	4.10-6.20 (21)	1.63±1.22 (20)	1.36±0.85 (21)	21.74±15.51 (21)	36.18±27.78 (21)	14.94±3.83 (21)	0.02±0.02 (21)	0.13±0.11 (21)	0.47±0.20 (21)	0.90±0.52 (21)	1.07±0.58 (21)	2.35±1.28 (21)
Scirpus olneyi	3.70-6.90 (66)	7.23±5.10 (63)	1.25±0.67 (66)	20.72±11.99 (66)	35.31±21.07 (66)	16.26±3.58 (66)	0.03±0.02 (66)	0.19±0.11 (66)	0.28±0.28 (66)	0.88±0.35 (66)	2.71±1.34 (66)	6.40±3.35 (66)
Scirpus robustus	4.00-6.90 (68)	8.90±5.30 (61)	0.80±0.57 (68)	13.02±10.13 (68)	22.41±17.45 (68)	16.08±3.62 (68)	0.05±0.03 (68)	0.27±0.13 (68)	0.36±0.48 (68)	0.96±0.35 (68)	3.54±4.60 (68)	6.78±3.59 (68)
Scirpus validus	5.30-5.80 (3)	1.12±0.67 (3)	1.36±1.22 (3)	20.40±20.53 (3)	35.17±35.39 (3)	13.91±1.98 (3)	0.05±0.07 (3)	0.10±0.09 (3)	0.55±0.16 (3)	0.53±0.30 (3)	0.54±0.12 (3)	1.63±0.74 (3)
Sesbania exaltata	4.00-7.50 (18)	2.59±1.93 (17)	1.28±0.94 (18)	20.84±15.69 (18)	35.93±27.05 (18)	15.93±4.62 (18)	0.04±0.05 (18)	0.14±0.13 (18)	0.46±0.26 (18)	0.79±0.59 (18)	1.34±0.88 (18)	3.22±2.14 (18)

(continued)

			DRY WEIGHT BASIS				WET WEIGHT BASIS					
Plant Species	pH Range	Water Salinity (ppt)	Nitrogen (%)	Carbon (%)	Organic Matter (%)	C/N	Phosphorus (ppt)	Potassium (ppt)	Calcium (ppt)	Magnesium (ppt)	Sodium (ppt)	Total Soil Salts (ppt)
Sesuvium maritimum	7.60-7.90 (3)	19.58±14.43 (3)	0.01±0.00 (3)	0.10±0.04 (3)	0.17±0.06 (3)	10.00±3.61 (3)	0.09±0.01 (3)	0.06±0.04 (3)	0.32±0.06 (3)	0.33±0.14 (3)	0.71±0.77 (3)	1.80±2.73 (3)
Setaria glauca	5.00-7.50 (12)	5.58±3.58 (12)	1.47±0.70 (12)	25.11±14.03 (12)	43.29±24.20 (12)	16.27±3.56 (12)	0.02±0.04 (12)	0.15±0.13 (12)	0.53±0.19 (12)	0.88±0.48 (12)	1.91±0.93 (12)	4.61±3.14 (12)
Setaria magna	4.00-5.90 (15)	4.96±3.36 (15)	2.15±0.75 (15)	34.45±13.42 (15)	59.39±23.14 (15)	15.77±1.97 (15)	0.01±0.01 (15)	0.09±0.07 (15)	0.35±0.28 (15)	0.63±0.37 (15)	1.78±0.87 (15)	4.39±2.50 (15)
Solidago sp.	4.90-7.80 (9)	1.81±1.53 (6)	1.26±1.07 (9)	21.43±18.33 (9)	37.04±31.68 (9)	17.90±3.40 (9)	0.05±0.06 (9)	0.13±0.13 (9)	1.16±1.02 (9)	0.66±0.68 (9)	1.16±1.25 (9)	2.82±3.10 (9)
Spartina alterniflora	4.50±8.50 (95)	15.19±7.78 (86)	0.68±0.56 (95)	12.32±10.87 (95)	21.24±18.74 (95)	18.35±6.66 (95)	0.07±0.06 (95)	0.30±0.11 (95)	0.31±0.37 (95)	1.03±0.36 (95)	3.97±1.73 (95)	10.10±4.38 (95)
Spartina cynosuroides	4.30-6.90 (31)	8.78±4.96 (27)	0.65±0.36 (31)	10.82±6.31 (31)	18.66±10.89 (31)	16.69±3.56 (31)	0.05±0.04 (31)	0.26±0.12 (31)	0.39±0.37 (31)	0.90±0.27 (31)	2.89±1.34 (31)	7.01±4.29 (31)
Spartina patens	3.70-7.90 (190)	8.55±6.33 (173)	1.04±0.67 (190)	17.31±12.05 (190)	29.70±20.87 (190)	16.15±3.72 (190)	0.04±0.04 (190)	0.21±0.12 (190)	0.32±0.34 (190)	0.97±0.38 (190)	3.00±3.04 (190)	6.81±4.06 (190)
Spartina spartineae	5.50-7.50 (7)	3.70±0.59 (4)	0.35±0.15 (7)	4.72±1.63 (7)	11.57±7.63 (7)	14.04±2.51 (7)	0.07±0.05 (7)	0.29±0.18 (7)	0.82±0.40 (7)	1.23±0.58 (7)	1.77±1.07 (7)	2.20±0.79 (7)
Spirodela polyrhiza	5.20-7.10 (4)	0.45±0.00 (1)	1.11±1.15 (4)	17.28±20.21 (4)	29.79±34.85 (4)	14.23±3.42 (4)	0.07±0.07 (4)	0.08±0.07 (4)	0.99±1.49 (4)	0.65±0.48 (4)	0.21±0.09 (4)	0.51±0.43 (4)
Taxodium distichlis	4.90-5.90 (5)	1.90±1.40 (5)	2.22±0.70 (5)	35.47±8.70 (5)	61.32±15.01 (5)	16.39±2.65 (5)	0.01±0.00 (5)	0.03±0.01 (5)	0.27±0.13 (5)	0.28±0.08 (5)	0.76±0.44 (5)	1.98±1.03 (5)
Typha angustifolia	3.70-8.50 (56)	3.93±4.06 (50)	1.71±0.92 (56)	28.55±15.89 (56)	49.13±27.37 (56)	17.05±4.25 (56)	0.02±0.04 (56)	0.10±0.09 (56)	0.51±0.44 (56)	0.62±0.57 (56)	1.43±1.36 (56)	3.64±3.65 (56)
Utricularia cornuta	4.60-5.90 (10)	0.69±0.65 (10)	1.73±1.01 (10)	26.08±17.05 (10)	44.97±29.40 (10)	14.26±2.65 (10)	0.01±0.01 (10)	0.06±0.05 (10)	0.36±0.18 (10)	0.60±0.41 (10)	0.58±0.40 (10)	1.19±0.94 (10)
Vigna repens	4.00-7.20 (36)	3.85±4.17 (33)	1.33±0.77 (36)	22.09±13.84 (36)	37.95±23.76 (36)	16.17±3.45 (36)	0.02±0.03 (36)	0.11±0.09 (36)	0.50±0.34 (36)	0.68±0.38 (36)	1.26±1.12 (36)	3.32±2.99 (36)
Zizaniopsis miliacea	4.30-6.00 (15)	1.36±1.90 (13)	1.80±0.94 (15)	28.04±15.41 (15)	48.35±26.57 (15)	15.16±1.93 (15)	0.02±0.03 (15)	0.07±0.11 (15)	0.82±0.41 (15)	0.44±0.48 (15)	0.52±0.52 (15)	1.47±1.47 (15)

*Number in parenthesis is number of samples taken (N).
**Standard deviation.

Table 16. Soil and water chemical characteristics of the saline vegetative type by hydrologic unit

Variable	No. of Samples	Mean	Standard Deviation	Range
		Hydrologic Unit 1		
Water salinity (ppt)	26	17.98	7.32	.63 - 29.57
Total soil salts (ppt)	15	10.33	2.70	4.95 - 17.13
Organic matter (%)	15	10.87	6.52	.19 - 25.26
Nitrogen (%)	15	.36	.21	.01 - .75
C/N ratio	15	17.35	4.65	11.00 - 26.02
Phosphorus (ppt)	15	.08	.04	.01 - .22
Potassium (ppt)	15	.31	.08	.10 - .41
Calcium (ppt)	15	.38	.54	.05 - 2.1
Magnesium (ppt)	15	1.04	.34	.48 - 2.06
Sodium (ppt)	15	4.50	1.87	.55 - 7.60
pH	15	6.08	.80	4.80 - 7.80
		Hydrologic Unit 2		
Water salinity (ppt)	15	19.24	10.21	11.72 - 51.88
Total soil salts (ppt)	9	10.16	4.31	4.96 - 18.88
Organic matter (%)	9	23.03	23.42	5.81 - 66.44
Nitrogen (%)	9	.65	.73	.23 - 2.53
C/N ratio	9	20.78	9.23	13.72 - 43.79
Phosphorus (ppt)	9	.09	.05	.02 - .18
Potassium (ppt)	9	.36	.13	.14 - .57
Calcium (ppt)	9	.25	.18	.06 - .70
Magnesium (ppt)	9	1.03	.29	.74 - 1.74
Sodium (ppt)	9	4.71	2.51	2.39 - 10.70
pH	9	6.27	.62	5.10 - 7.10
		Hydrologic Unit 4		
Water salinity (ppt)	22	15.84	3.84	6.26 - 21.86
Total soil salts (ppt)	19	9.69	2.82	2.84 - 13.94
Organic matter (%)	19	25.48	19.25	1.43 - 62.39
Nitrogen (%)	19	.86	.69	.05 - 2.14
C/N ratio	19	18.29	6.03	12.92 - 41.33
Phosphorus (ppt)	19	.06	.05	.004- .19
Potassium (ppt)	19	.29	.08	.15 - .48
Calcium (ppt)	19	.49	.89	.06 - 3.82
Magnesium (ppt)	19	.92	.11	.74 - 1.17
Sodium (ppt)	19	3.77	.76	2.54 - 5.05
pH	19	6.23	.59	4.90 - 7.20
		Hydrologic Unit 5		
Water salinity (ppt)	30	17.37	6.39	8.07 - 32.39
Total soil salts (ppt)	23	11.47	4.81	.58 - 18.92
Organic matter (%)	23	16.57	9.20	4.59 - 37.67
Nitrogen (%)	23	.57	.28	.21 - 1.28
C/N ratio	23	17.18	6.31	11.67 - 41.72
Phosphorus (ppt)	23	.07	.03	.01 - .16
Potassium (ppt)	23	.37	.08	.19 - .53
Calcium (ppt)	23	.45	.54	.07 - 2.44
Magnesium (ppt)	23	1.03	.20	.69 - 1.49
Sodium (ppt)	23	4.75	1.48	2.47 - 7.74
pH	23	6.18	.52	5.10 - 6.80

(Continued)

Table 16. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
		Hydrologic Unit 7		
Water salinity (ppt)	2	10.63	12.48	1.80 - 19.46
Total soil salts (ppt)	1	8.21	- -	8.21 - 8.21
Organic matter (%)	1	6.07	- -	6.07 - 6.07
Nitrogen (%)	1	.28	- -	.28 - .28
C/N ratio	1	12.57	- -	12.57 - 12.57
Phosphorus (ppt)	1	.06	- -	.06 - .06
Potassium (ppt)	1	.42	- -	.42 - .42
Calcium (ppt)	1	.51	- -	.51 - .51
Magnesium (ppt)	1	1.41	- -	1.41 - 1.41
Sodium (ppt)	1	39.17	- -	39.17 - 39.17
pH	1	6.40	- -	6.40 - 6.40
		Hydrologic Unit 8		
Water salinity (ppt)	3	14.16	5.94	9.32 - 20.80
Total soil salts (ppt)	3	9.55	5.21	.56 - 15.48
Organic matter (%)	3	8.09	1.91	6.14 - 9.95
Nitrogen (%)	3	.32	.07	.25 - .39
C/N ratio	3	14.46	2.40	12.17 - 16.97
Phosphorus (ppt)	3	.07	.009	.06 - .07
Potassium (ppt)	3	.47	.05	.43 - .52
Calcium (ppt)	3	.46	.08	.37 - .54
Magnesium (ppt)	3	1.47	.17	1.28 - 1.59
Sodium (ppt)	3	4.28	.61	3.70 - 4.93
pH	3	6.56	.32	6.20 - 6.80
		Hydrologic Unit 9		
Water salinity (ppt)	- -	- -	- -	- -
Total soil salts (ppt)	1	3.07	- -	3.07 - 3.07
Organic matter (%)	1	2.14	- -	2.14 - 2.14
Nitrogen (%)	1	.06	- -	.06 - .06
C/N ratio	1	20.66	- -	20.66 - 20.66
Phosphorus (ppt)	1	.13	- -	.13 - .13
Potassium (ppt)	1	.29	- -	.29 - .29
Calcium (ppt)	1	7.28	- -	7.28 - 7.28
Magnesium (ppt)	1	3.22	- -	3.22 - 3.22
Sodium (ppt)	1	2.55	- -	2.55 - 2.55
pH	1	7.70	- -	7.70 - 7.70

Table 17. Soil and water chemical characteristics of the brackish vegetative type by hydrologic unit

Variable	No. of Samples	Mean	Standard Deviation	Range
Hydrologic Unit 1				
Water salinity (ppt)	31	10.87	3.77	4.67 - 18.39
Total soil salts (ppt)	25	7.36	1.96	3.75 - 10.35
Organic matter (%)	25	29.22	19.25	3.67 - 85.72
Nitrogen (%)	25	1.01	.93	.11 - 5.00
C/N ratio	25	19.22	5.82	1.76 - 32.07
Phosphorus (ppt)	25	.04	.04	.007- .23
Potassium (ppt)	25	0.23	.10	.11 - .57
Calcium (ppt)	25	.18	.41	.04 - 2.13
Magnesium (ppt)	25	.83	.27	.53 - 1.93
Sodium (ppt)	25	3.22	.92	1.60 - 4.92
pH	25	5.45	.87	3.70 - 7.80
Hydrologic Unit 2				
Water salinity (ppt)	17	11.55	3.27	4.35 - 14.96
Total soil salts (ppt)	16	8.94	4.10	4.85 - 21.25
Organic matter (%)	16	29.25	16.94	1.95 - 57.83
Nitrogen (%)	16	1.16	.72	.08 - 2.66
C/N ratio	16	14.10	4.79	1.00 - 20.48
Phosphorus (ppt)	16	.03	.03	.01 - .11
Potassium (ppt)	16	.21	.06	.15 - .39
Calcium (ppt)	16	.20	.21	.05 - .72
Magnesium (ppt)	16	.87	.15	.62 - 1.17
Sodium (ppt)	16	3.43	.86	1.72 - 4.90
pH	16	5.56	.92	4.00 - 6.90
Hydrologic Unit 3				
Water salinity (ppt)	8	8.54	5.69	1.34 - 17.51
Total soil salts (ppt)	6	7.82	3.51	3.63 - 13.38
Organic matter (%)	6	26.43	29.61	4.98 - 72.75
Nitrogen (%)	6	.69	.73	.10 - 1.89
C/N ratio	6	23.81	12.51	12.69 - 45.20
Phosphorus (ppt)	6	.10	.07	.01 - .19
Potassium (ppt)	6	.23	.09	.12 - .35
Calcium (ppt)	6	.64	.97	.08 - 2.50
Magnesium (ppt)	6	.94	.26	.70 - 1.42
Sodium (ppt)	6	2.24	1.31	.60 - 3.82
pH	6	5.86	.82	5.10 - 7.30
Hydrologic Unit 4				
Water salinity (ppt)	21	9.68	5.11	3.28 - 28.08
Total soil salts (ppt)	21	7.44	3.39	2.10 - 15.17
Organic matter (%)	21	48.74	18.92	14.72 - 77.25
Nitrogen (%)	21	1.59	.611	.64 - 2.47
C/N ratio	21	18.07	4.76	13.31 - 36.20
Phosphorus (ppt)	21	.01	.01	.003- .063
Potassium (ppt)	21	.16	.06	.07 - .34
Calcium (ppt)	21	.17	.10	.03 - .41
Magnesium (ppt)	21	.76	.21	.44 - 1.45
Sodium (ppt)	21	3.19	1.10	1.47 - 5.94
pH	21	5.48	.58	4.40 - 6.40

(Continued)

Table 17. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
Hydrologic Unit 5				
Water salinity (ppt)	18	7.61	4.78	2.42 - 18.50
Total soil salts (ppt)	17	5.95	2.76	1.84 - 11.61
Organic matter (%)	17	43.21	20.45	16.03 - 73.68
Nitrogen (%)	17	1.51	.71	.54 - 2.57
C/N ratio	17	16.59	1.79	14.30 - 21.70
Phosphorus (ppt)	17	.02	.02	.003- .07
Potassium (ppt)	17	.24	.25	.06 - 1.17
Calcium (ppt)	17	.29	.31	.02 - 1.32
Magnesium (ppt)	17	1.12	1.43	.48 - 6.63
Sodium (ppt)	17	5.20	8.73	1.23 - 38.72
pH	17	5.47	.63	4.00 - 6.70
Hydrologic Unit 7				
Water salinity (ppt)	23	4.48	4.38	.42 - 15.72
Total soil salts (ppt)	18	6.14	.35	1.86 - 12.70
Organic matter (%)	18	32.55	17.44	6.88 - 66.70
Nitrogen (%)	18	1.16	.53	.34 - 2.13
C/N ratio	18	15.53	2.30	11.73 - 19.54
Phosphorus (ppt)	18	.02	.02	.002- .08
Potassium (ppt)	18	.21	.90	.04 - .38
Calcium (ppt)	18	.51	.29	.09 - 1.03
Magnesium (ppt)	18	1.12	.30	.50 - 1.69
Sodium (ppt)	18	2.45	1.20	.37 - 5.15
pH	18	5.64	.42	4.80 - 6.50
Hydrologic Unit 8				
Water salinity (ppt)	10	6.03	4.15	.99 - 12.69
Total soil salts (ppt)	12	6.67	3.17	1.04 - 12.10
Organic matter (%)	12	18.36	10.60	2.05 - 35.20
Nitrogen (%)	12	.70	.39	.12 - 1.41
C/N ratio	12	14.55	2.10	9.92 - 17.68
Phosphorus (ppt)	12	.05	.03	.02 - .10
Potassium (ppt)	12	.27	.98	.17 - .50
Calcium (ppt)	12	.43	.33	.06 - 1.18
Magnesium (ppt)	12	1.12	.24	.79 - 1.54
Sodium (ppt)	12	3.04	1.26	.89 - 4.66
pH	12	6.09	.49	5.50 - 6.90
Hydrologic Unit 9				
Water salinity (ppt)	21	6.41	4.38	.49 - 15.79
Total soil salts (ppt)	21	6.60	3.11	1.48 - 12.56
Organic matter (%)	21	18.93	10.48	7.65 - 52.05
Nitrogen (%)	21	.72	.30	.27 - 1.49
C/N ratio	21	14.74	2.49	10.50 - 20.26
Phosphorus (ppt)	21	.03	.03	.004- 1.29
Potassium (ppt)	21	.32	.14	.11 - .59
Calcium (ppt)	21	.51	.33	.12 - 1.28
Magnesium (ppt)	21	1.37	.35	.78 - 2.10
Sodium (ppt)	21	3.34	1.23	1.27 - 5.68
pH	21	6.16	.36	5.20 - 6.80

Table 18. Soil and water chemical characteristics of the intermediate vegetative type by hydrologic unit

Variable	No. of Samples	Mean	Standard Deviation	Range
		Hydrologic Unit 1		
Water salinity (ppt)	2	2.74	.04	2.71 - 2.77
Total soil salts (ppt)	2	3.99	.96	3.31 - 4.67
Organic matter (%)	2	38.21	38.48	11.00 - 65.43
Nitrogen (%)	2	1.29	1.67	.43 - 2.26
C/N ratio	2	15.81	1.38	14.83 - 16.79
Phosphorus (ppt)	2	.04	.05	.004- .08
Potassium (ppt)	2	.18	.17	.06 - .30
Calcium (ppt)	2	.09	.05	.05 - .14
Magnesium (ppt)	2	.63	.31	.40 - .85
Sodium (ppt)	2	1.68	.28	1.48 - 1.88
pH	2	5.40	.56	5.00 - 5.80
		Hydrologic Unit 2		
Water salinity (ppt)	1	4.58	- -	4.58 - 4.58
Total soil salts (ppt)	1	3.53	- -	3.53 - 3.53
Organic matter (%)	1	69.03	- -	69.03 - 69.03
Nitrogen (%)	1	1.95	- -	1.95 - 1.95
C/N ratio	1	20.53	- -	20.53 - 20.53
Phosphorus (ppt)	1	.005	- -	.005- .005
Potassium (ppt)	1	.05	- -	.05 - .05
Calcium (ppt)	1	.03	- -	.03 - .03
Magnesium (ppt)	1	.41	- -	.41 - .41
Sodium (ppt)	1	1.46	- -	1.46 - 1.46
pH	1	3.80	- -	3.80 - 3.80
		Hydrologic Unit 3		
Water salinity (ppt)	7	2.55	2.33	.49 - 5.93
Total soil salts (ppt)	7	2.86	1.52	.24 - 4.58
Organic matter (%)	7	11.99	20.60	.64 - 58.44
Nitrogen (%)	7	.55	1.01	.02 - 2.83
C/N ratio	7	14.54	2.88	11.22 - 18.50
Phosphorus (ppt)	7	.13	.05	.02 - .20
Potassium (ppt)	7	.22	.16	.06 - .57
Calcium (ppt)	7	1.12	.84	.18 - 2.41
Magnesium (ppt)	7	1.08	.53	.33 - 2.05
Sodium (ppt)	7	1.45	.99	.50 - 3.01
pH	7	6.97	.90	5.80 - 8.10

(Continued)

Table 18. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
		Hydrologic Unit 4		
Water salinity (ppt)	3	5.42	2.68	2.67 - 8.04
Total soil salts (ppt)	3	3.32	.50	2.86 - 3.87
Organic matter (%)	3	64.97	11.10	52.38 - 73.34
Nitrogen (%)	3	2.59	.60	1.93 - 3.10
C/N ratio	3	14.70	1.52	12.94 - 15.74
Phosphorus (ppt)	3	.003	7.24	.003- .004
Potassium (ppt)	3	.05	.005	.04 - .05
Calcium (ppt)	3	.22	.13	.12 - .38
Magnesium (ppt)	3	.37	.06	.30 - .43
Sodium (ppt)	3	1.43	.12	1.31 - 1.56
pH	3	5.57	.42	5.10 - 5.90
		Hydrologic Unit 5		
Water salinity (ppt)	7	4.68	3.40	.34 - 9.80
Total soil salts (ppt)	4	4.88	2.85	2.35 - 9.72
Organic matter (%)	4	62.70	20.98	33.50 - 79.13
Nitrogen (%)	4	2.25	.61	1.55 - 2.97
C/N ratio	4	15.92	2.70	12.53 - 18.36
Phosphorus (ppt)	4	.006	.002	.003- .008
Potassium (ppt)	4	.07	.03	.03 - .11
Calcium (ppt)	4	.50	.33	.14 - .93
Magnesium (ppt)	4	.55	.14	.41 - .71
Sodium (ppt)	4	1.53	.77	.49 - 2.18
pH	4	5.37	.29	5.00 - 5.70
		Hydrologic Unit 7		
Water salinity (ppt)	12	2.07	1.66	.35 - 5.99
Total soil salts (ppt)	11	2.21	.18	.55 - 7.15
Organic matter (%)	11	24.93	21.64	8.02 - 82.75
Nitrogen (%)	11	.88	.42	.33 - 2.34
C/N ratio	11	15.29	4.03	12.68 - 20.51
Phosphorus (ppt)	11	.03	.94	.003 - .01
Potassium (ppt)	11	.15	.09	.05 - .31
Calcium (ppt)	11	.76	.42	.08 - 1.28
Magnesium (ppt)	11	1.68	1.85	.47 - 7.12
Sodium (ppt)	11	.90	.43	.19 - 1.70
pH	11	5.73	.43	5.30 - 6.50

(Continued)

Table 18. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
Hydrologic Unit 8				
Water salinity (ppt)	9	1.85	.65	.53 - 5.38
Total soil salts (ppt)	8	2.39	1.36	.64 - 4.30
Organic matter (%)	8	21.11	13.71	6.81 - 52.50
Nitrogen (%)	8	.79	.31	.35 - 1.35
C/N ratio	8	14.69	3.94	11.28 - 22.55
Phosphorus (ppt)	8	.03	.02	.006- .09
Potassium (ppt)	8	.21	.09	.07 - .37
Calcium (ppt)	8	.67	.29	1.11 - .44
Magnesium (ppt)	8	1.45	.31	1.04 - 1.93
Sodium (ppt)	8	1.44	.56	.76 - 2.42
pH	8	5.70	.37	5.10 - 6.10
Hydrologic Unit 9				
Water salinity (ppt)	10	2.43	1.45	.90 - 6.04
Total soil salts (ppt)	11	5.12	4.52	.55 - 16.53
Organic matter (%)	11	28.35	22.51	2.60 - 69.19
Nitrogen (%)	11	1.05	.53	.39 - 2.20
C/N ratio	11	15.62	4.49	8.19 - 24.14
Phosphorus (ppt)	11	.01	.01	.002- .05
Potassium (ppt)	11	.16	.09	.05 - .31
Calcium (ppt)	11	.63	.42	.13 - 1.45
Magnesium (ppt)	11	1.30	.72	.40 - 3.06
Sodium (ppt)	11	2.20	1.50	.42 - 5.88
pH	11	5.78	.38	5.30 - 6.30

Table 19. Soil and water chemical characteristics of the fresh vegetative type by hydrologic unit

Variable	No. of Samples	Mean	Standard Deviation	Range
Hydrologic Unit 1				
Water salinity (ppt)	5	3.98	2.11	1.09 - 6.66
Total soil salts (ppt)	3	2.49	.49	2.13 - 3.04
Organic matter (%)	3	52.99	23.77	25.77 - 69.67
Nitrogen (%)	3	1.67	1.00	.63 - 2.64
C/N ratio	3	19.97	4.28	15.30 - 23.73
Phosphorus (ppt)	3	.01	.01	.002- .024
Potassium (ppt)	3	.05	.02	.02 - .08
Calcium (ppt)	3	.14	.08	.06 - .23
Magnesium (ppt)	3	.35	.09	.29 - .46
Sodium (ppt)	3	.76	.12	.71 - .81
pH	3	4.76	.23	4.50 - 4.90

(Continued)

Table 19. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
		Hydrologic Unit 3		
Water salinity (ppt)	12	.89	.63	.37 - 2.64
Total soil salts (ppt)	9	1.24	1.13	.30 - 3.88
Organic matter (%)	9	6.22	3.55	2.91 - 12.38
Nitrogen (%)	9	.23	.15	.09 - .59
C/N ratio	9	16.39	4.24	22.81 - .25
Phosphorus (ppt)	9	.17	.08	.08 - .30
Potassium (ppt)	9	.16	.05	.09 - .24
Calcium (ppt)	9	1.49	.97	.27 - 3.08
Magnesium (ppt)	9	.99	.25	.56 - 1.38
Sodium (ppt)	9	.39	.20	.19 - .84
pH	9	6.61	.72	5.30 - 7.20
		Hydrologic Unit 4		
Water salinity (ppt)	24	1.81	1.22	.100- 4.51
Total soil salts (ppt)	25	1.79	1.11	.06 - 4.09
Organic matter (%)	25	67.35	18.58	23.12 - 89.03
Nitrogen (%)	25	2.28	.60	.79 - 3.12
C/N ratio	25	17.28	2.22	11.04 - 22.60
Phosphorus (ppt)	25	.007	.006	.002- .027
Potassium (ppt)	25	.02	.01	.004- .06
Calcium (ppt)	25	.44	.30	.07 - 1.23
Magnesium (ppt)	25	.22	.13	.03 - .54
Sodium (ppt)	25	.64	.45	.02 - 1.49
pH	25	5.10	.42	4.10 - 5.90
		Hydrologic Unit 5		
Water salinity (ppt)	30	.73	.92	.09 - 4.54
Total soil salts (ppt)	28	1.48	2.19	.003- 9.07
Organic matter (%)	28	67.57	22.31	7.69 - 88.77
Nitrogen (%)	28	2.37	.74	.39 - 3.35
C/N ratio	28	16.40	3.28	10.33 - 24.22
Phosphorus (ppt)	28	.008	.009	.001- .04
Potassium (ppt)	28	.04	.04	.008- .20
Calcium (ppt)	28	.84	.62	.05 - 2.10
Magnesium (ppt)	28	.40	.46	.08 - 2.25
Sodium (ppt)	28	.46	.63	.05 - 2.43
pH	28	5.24	.43	4.30 - 6.30

(Continued)

Table 19. (Continued)

Variable	No. of Samples	Mean	Standard Deviation	Range
Hydrologic Unit 6				
Water salinity (ppt)	7	.42	.29	.26 - 1.09
Total soil salts (ppt)	3	.54	.28	.30 - .85
Organic matter (%)	3	23.27	11.05	15.84 - 35.98
Nitrogen (%)	3	.93	.40	.65 - 1.40
C/N ratio	3	14.38	.45	14.10 - 14.90
Phosphorus (ppt)	3	.02	.01	.009- .03
Potassium (ppt)	3	.08	.04	.03 - .12
Calcium (ppt)	3	1.15	.15	.97 - 1.29
Magnesium (ppt)	3	.42	.10	.30 - .50
Sodium (ppt)	3	.18	.14	.06 - .35
pH	3	5.50	.45	5.00 - 5.90
Hydrologic Unit 7				
Water salinity (ppt)	6	2.20	2.28	.20 - 5.77
Total soil salts (ppt)	6	1.83	.14	.59 - 4.90
Organic matter (%)	6	60.13	25.96	16.10 - 87.49
Nitrogen (%)	6	1.83	.46	.64 - 2.63
C/N ratio	6	19.13	2.91	14.59 - 50.75
Phosphorus (ppt)	6	.004	.002	.003- .024
Potassium (ppt)	6	.04	.02	.017 - .12
Calcium (ppt)	6	.76	.042	.49 - 1.07
Magnesium (ppt)	6	.73	.35	.24 - 1.31
Sodium (ppt)	6	.95	.94	.09 - 2.71
pH	6	5.15	.46	4.50 - 5.90
Hydrologic Unit 8				
Water salinity (ppt)	31	.41	.26	.06 - 1.18
Total soil salts (ppt)	19	1.03	.77	.02 - 2.44
Organic matter (%)	19	35.07	26.41	1.76 - 84.68
Nitrogen (%)	19	1.39	.91	.09 - 3.23
C/N ratio	19	13.59	2.78	8.03 - 17.87
Phosphorus (ppt)	19	.01	.01	.001- .03
Potassium (ppt)	19	.07	.05	.01 - .20
Calcium (ppt)	19	.57	.25	.24 - 1.24
Magnesium (ppt)	19	.66	.41	.20 - 1.51
Sodium (ppt)	19	.51	.36	.07 - 1.31
pH	19	5.41	.37	4.50 - 6.00
Hydrologic Unit 9				
Water salinity (ppt)	6	1.27	.89	.33 - 2.89
Total soil salts (ppt)	3	1.60	1.32	.27 - 2.92
Organic matter (%)	3	11.92	8.07	6.14 - 21.14
Nitrogen (%)	3	.54	.38	.27 - .98
C/N ratio	3	12.88	.34	12.51 - 13.18
Phosphorus (ppt)	3	.03	.02	.009- .06
Potassium (ppt)	3	.14	.12	.06 - .29
Calcium (ppt)	3	.71	.60	.04 - 1.22
Magnesium (ppt)	3	1.04	.29	.75 - 1.35
Sodium (ppt)	3	1.00	.16	.81 - 1.10
pH	3	5.60	.60	5.00 - 6.20

Table 20. Water salinity (ppt) by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
		Saline Vegetative Type		
1	26	17.98	7.32	.63 - 29.57
2	15	19.24	10.21	11.72 - 51.88
3	- -	- -	- -	- -
4	22	15.84	3.84	6.26 - 21.86
5	30	17.37	6.39	8.07 - 32.39
6	- -	- -	- -	- -
7	2	10.63	12.48	1.80 - 19.46
8	3	14.16	5.94	9.32 - 20.80
9	- -	- -	- -	- -
		Brackish Vegetative Type		
1	31	10.81	3.77	4.67 - 18.39
2	17	11.55	3.27	4.35 - 14.96
3	8	8.54	5.69	1.34 - 17.51
4	21	9.68	5.11	3.28 - 28.08
5	18	7.61	4.78	2.42 - 18.50
6	- -	- -	- -	- -
7	23	4.48	4.38	.42 - 15.72
8	10	6.03	4.15	.99 - 12.69
9	21	6.41	4.38	.49 - 15.79
		Intermediate Vegetative Type		
1	2	2.74	.04	2.71 - 2.77
2	1	4.58	- -	4.58 - 4.58
3	7	2.55	2.23	.49 - 5.93
4	3	5.42	2.68	2.67 - 8.04
5	7	4.68	3.40	.34 - 9.80
6	- -	- -	- -	- -
7	12	2.07	1.66	.35 - 5.99
8	9	1.85	1.65	.53 - 5.38
9	10	2.43	1.45	.90 - 6.04
		Fresh Vegetative Type		
1	5	3.98	2.11	1.09 - 6.66
2	- -	- -	- -	- -
3	12	.89	.63	.37 - 2.64
4	24	1.81	1.22	.100- 4.51
5	30	.73	.92	.09 - 4.54
6	7	.42	.29	.26 - 1.09
7	6	2.20	2.28	.20 - 5.77
8	31	.41	.26	.06 - 1.18
9	6	1.27	.89	.33 - 2.89

Table 21. Total soil salts (ppt) by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
Saline Vegetative Type				
1	15	10.33	2.70	.63 - 29.57
2	9	10.16	4.31	4.96 - 18.88
3	- -	- -	- -	- -
4	19	9.69	2.82	2.84 - 13.94
5	23	11.47	4.81	.58 - 18.92
6	- -	- -	- -	- -
7	1	8.21	- -	8.21 - 8.21
8	3	9.55	5.21	.56 - 15.48
9	1	3.07	- -	3.07 - 3.07
Brackish Vegetative Type				
1	25	7.36	1.96	3.75 - 10.35
2	16	8.94	4.10	4.85 - 21.25
3	6	7.82	3.51	3.63 - 13.38
4	21	7.44	3.39	2.10 - 15.17
5	17	5.95	2.76	1.84 - 11.61
6	- -	- -	- -	- -
7	18	6.14	.35	1.86 - 12.70
8	12	6.67	3.17	1.04 - 12.10
9	21	6.60	3.11	1.48 - 12.56
Intermediate Vegetative Type				
1	2	3.99	.96	3.31 - 4.67
2	1	3.53	- -	3.53 - 3.53
3	7	2.86	1.52	.24 - 4.58
4	3	3.32	.50	2.86 - 3.87
5	4	4.88	2.85	2.35 - 8.72
6	- -	- -	- -	- -
7	11	2.21	.18	.55 - 7.15
8	8	2.39	1.36	.64 - 4.30
9	11	5.12	4.52	.55 - 16.53
Fresh Vegetative Type				
1	3	2.49	.48	2.13 - 3.04
2	- -	- -	- -	- -
3	9	1.24	1.13	.30 - 3.88
4	25	1.79	1.11	.06 - 4.09
5	28	1.48	2.19	.003- 9.07
6	3	.54	.28	.30 - .85
7	6	1.83	.14	.59 - 4.90
8	19	1.03	.77	.02 - 2.44
9	3	1.60	1.32	.27 - 2.92

Table 22. Organic matter content (percent) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
Saline Vegetative Type				
1	15	10.87	6.52	.19 - 25.26
2	9	23.03	23.42	5.81 - 66.44
3	- -	- -	- -	- -
4	19	25.48	19.25	1.43 - 62.39
5	23	16.57	9.20	4.59 - 37.67
6	- -	- -	- -	- -
7	1	6.07	- -	6.07 - 6.07
8	3	8.09	1.91	6.14 - 9.95
9	1	2.14	- -	2.14 - 2.14
Brackish Vegetative Type				
1	25	29.22	19.25	3.67 - 85.72
2	16	29.25	16.94	1.95 - 57.83
3	6	26.43	29.61	4.98 - 72.75
4	21	48.74	18.92	14.72 - 77.25
5	17	43.21	20.45	16.03 - 73.68
6	- -	- -	- -	- -
7	18	32.55	17.44	6.88 - 66.70
8	12	18.36	10.60	2.05 - 35.20
9	21	18.93	10.48	7.65 - 52.05
Intermediate Vegetative Type				
1	2	38.21	38.48	11.00 - 65.43
2	1	69.03	- -	69.03 - 69.03
3	7	11.99	20.60	.64 - 58.44
4	3	64.97	11.10	52.38 - 73.34
5	4	62.70	20.98	33.50 - 79.13
6	- -	- -	- -	- -
7	11	24.93	21.64	8.02 - 82.75
8	8	21.11	13.71	6.81 - 52.50
9	11	28.35	22.51	2.60 - 69.19
Fresh Vegetative Type				
1	3	52.99	23.77	25.77 - 69.67
2	- -	- -	- -	- -
3	9	6.22	3.55	2.91 - 12.38
4	25	67.35	18.58	23.12 - 89.03
5	28	67.57	22.31	7.69 - 88.77
6	3	23.27	11.03	15.84 - 35.98
7	6	60.13	25.96	16.10 - 87.49
8	19	35.07	26.41	1.76 - 84.68
9	3	11.92	8.07	6.14 - 21.14

Table 23. Nitrogen content (percent) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
		Saline Vegetative Type		
1	15	.36	.21	.01 - .75
2	9	.65	.73	.23 - 2.53
3	- -	- -	- -	- -
4	19	.86	.69	.05 - 2.14
5	23	.57	.28	.21 - 1.28
6	- -	- -	- -	- -
7	1	.28	- -	.28 - .28
8	3	.32	.07	.25 - .39
9	1	.06	- -	.06 - .06
		Brackish Vegetative Type		
1	25	1.01	.93	.11 - 5.00
2	16	1.16	.72	.08 - 2.66
3	6	.69	.73	.10 - 1.89
4	21	1.59	.61	.64 - 2.47
5	17	1.51	.71	.54 - 2.57
6	- -	- -	- -	- -
7	18	1.16	.53	.34 - 2.13
8	12	.70	.39	.12 - 1.41
9	21	.72	.30	.27 - 1.49
		Intermediate Vegetative Type		
1	2	1.29	1.67	.43 - 2.26
2	1	1.95	- -	1.95 - 1.95
3	7	.55	1.01	.02 - 2.83
4	3	2.59	.60	1.93 - 3.10
5	4	2.25	.61	1.55 - 2.97
6	- -	- -	- -	- -
7	11	.88	.42	.33 - 2.34
8	8	.79	.31	.35 - 1.35
9	11	1.05	.53	.39 - 2.20
		Fresh Vegetative Type		
1	3	1.67	1.00	.63 - 2.64
2	- -	- -	- -	- -
3	9	.23	.15	.09 - .59
4	25	2.28	.60	.79 - 3.12
5	28	2.37	.74	.39 - 3.35
6	3	.93	.40	.65 - 1.40
7	6	1.83	.46	.64 - 2.63
8	19	1.39	.91	.09 - 3.23
9	3	.54	.38	.27 - .98

Table 24. Carbon/Nitrogen ratio of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
		Saline Vegetative Type		
1	15	17.35	4.65	11.00 - 26.02
2	9	20.78	9.23	13.72 - 43.79
3	- -	- -	- -	- -
4	19	18.29	6.03	12.92 - 41.33
5	23	17.18	6.31	11.67 - 41.72
6	- -	- -	- -	- -
7	1	12.57	- -	12.57 - 12.57
8	3	14.46	2.40	12.17 - 16.97
9	1	20.66	- -	20.66 - 20.66
		Brackish Vegetative Type		
1	25	19.22	5.82	1.76 - 32.07
2	16	14.10	4.79	1.00 - 20.48
3	6	23.81	12.51	12.69 - 45.20
4	21	18.07	4.76	13.31 - 36.20
5	17	16.59	1.79	14.30 - 21.70
6	- -	- -	- -	- -
7	18	15.53	2.30	11.73 - 19.54
8	12	14.55	2.10	9.92 - 17.68
9	21	14.74	2.49	10.50 - 20.26
		Intermediate Vegetative Type		
1	2	15.81	1.38	14.83 - 16.79
2	1	20.53	- -	20.53 - 20.53
3	7	14.54	2.88	11.22 - 18.50
4	3	14.70	1.52	12.94 - 15.74
5	4	15.92	2.70	12.53 - 18.36
6	- -	- -	- -	- -
7	11	15.29	4.03	12.68 - 20.51
8	8	14.69	3.94	11.28 - 22.55
9	11	15.62	4.49	8.19 - 24.14
		Fresh Vegetative Type		
1	3	19.97	4.28	15.30 - 23.73
2	- -	- -	- -	- -
3	9	16.39	4.24	10.56 - 22.82
4	25	17.28	2.22	11.04 - 22.60
5	28	16.40	3.28	10.33 - 24.22
6	3	14.38	.45	14.10 - 14.90
7	6	19.13	2.91	14.59 - 50.75
8	19	13.59	2.78	8.03 - 17.87
9	3	12.88	.34	12.51 - 13.18

Table 25. Phosphorus content (ppt) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
		Saline Vegetative Type		
1	15	.08	.04	.01 - .22
2	9	.09	.05	.02 - .18
3	- -	- -	- -	- -
4	19	.06	.05	.004- .19
5	23	.07	.03	.01 - .16
6	- -	- -	- -	- -
7	1	.06	- -	.06 - .06
8	3	.07	.009	.06 - .07
9	1	.13	- -	.13 - .13
		Brackish Vegetative Type		
1	25	.04	.04	.007- .23
2	16	.03	.03	.01 - .11
3	6	.10	.07	.01 - .19
4	21	.01	.01	.003- .063
5	17	.02	.02	.003- .07
6	- -	- -	- -	- -
7	18	.02	.02	.002- .08
8	12	.05	.03	.02 - .10
9	21	.03	.03	.004- .129
		Intermediate Vegetative Type		
1	2	.04	.05	.004- .08
2	1	.005	- -	.005- .005
3	7	.13	.05	.02 - .20
4	3	.003	7.24	.003- .004
5	4	.006	.002	.003- .008
6	- -	- -	- -	- -
7	11	.03	.94	.003- .01
8	8	.03	.02	.006- .09
9	11	.01	.01	.002- .05
		Fresh Vegetative Type		
1	3	.01	.01	.002- .024
2	- -	- -	- -	- -
3	9	.17	.08	.08 - .30
4	25	.007	.006	.002- .027
5	28	.008	.009	.001- .04
6	3	.02	.01	.009- .03
7	6	.004	.002	.003- .024
8	19	.01	.01	.001- .035
9	3	.03	.02	.009- .06

Table 26. Potassium content (ppt) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
Saline Vegetative Type				
1	15	.31	.08	.10 - .44
2	9	.36	.13	.14 - .57
3	- -	- -	- -	- -
4	19	.29	.08	.15 - .48
5	23	.37	.08	.19 - .53
6	- -	- -	- -	- -
7	1	.42	- -	.42 - .42
8	3	.47	.05	.43 - .52
9	1	.29	- -	.29 - .29
Brackish Vegetative Type				
1	25	.23	.10	.11 - .57
2	16	.21	.06	.15 - .39
3	6	.23	.09	.12 - .35
4	21	.16	.06	.07 - .34
5	17	.24	.25	.06 - 1.17
6	- -	- -	- -	- -
7	18	.21	.90	.04 - .38
8	12	.27	.98	.17 - .50
9	21	.32	.14	.11 - .59
Intermediate Vegetative Type				
1	2	.18	.17	.06 - .30
2	1	.05	- -	.05 - .05
3	7	.22	.16	.06 - .57
4	3	.05	.005	.04 - .05
5	4	.06	.03	.03 - .11
6	- -	- -	- -	- -
7	11	.15	.09	.05 - .31
8	8	.21	.09	.07 - .37
9	11	.16	.09	.05 - .31
Fresh Vegetative Type				
1	3	.05	.02	.02 - .08
2	- -	- -	- -	- -
3	9	.16	.05	.09 - .24
4	25	.02	.01	.004- .064
5	28	.04	.04	.008- .20
6	3	.08	.04	.03 - .12
7	6	.04	.02	.017- .12
8	19	.07	.05	.01 - .20
9	3	.14	.12	.06 - .29

Table 27. Calcium content (ppt) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
Saline Vegetative Type				
1	15	.38	.54	.05 - 2.10
2	9	.25	.18	.06 - .70
3	- -	- -	- -	- -
4	19	.49	.89	.06 - 3.82
5	23	.45	.54	.07 - 2.44
6	- -	- -	- -	- -
7	1	.51	- -	.51 - .51
8	3	.46	.08	.37 - .54
9	1	7.28	- -	7.28 - 7.28
Brackish Vegetative Type				
1	25	.18	.41	.04 - 2.13
2	16	.20	.21	.05 - .72
3	6	.64	.97	.08 - 2.50
4	21	.17	.10	.03 - .41
5	17	.29	.31	.02 - 1.32
6	- -	- -	- -	- -
7	18	.51	.29	.09 - 1.03
8	12	.43	.33	.06 - 1.18
9	21	.51	.33	.12 - 1.28
Intermediate Vegetative Type				
1	2	.09	.05	.05 - .14
2	1	.03	- -	.03 - .03
3	7	1.12	.84	.18 - 2.41
4	3	.22	.13	.12 - .38
5	4	.50	.33	.14 - .93
6	- -	- -	- -	- -
7	11	.76	.42	.08 - 1.28
8	8	.67	.29	1.11 - .44
9	11	.63	.42	.13 - 1.45
Fresh Vegetative Type				
1	3	.14	.08	.06 - .23
2	- -	- -	- -	- -
3	9	1.49	.97	.27 - 3.08
4	25	.44	.30	.07 - 1.23
5	28	.84	.62	.05 - 2.10
6	3	1.15	.15	.97 - 1.29
7	6	.76	.042	.49 - 1.07
8	19	.57	.25	.24 - 1.24
9	3	.71	.60	.04 - 1.22

Table 28. Magnesium content (ppt) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
	Saline Vegetative Type			
1	15	1.04	.34	.48 - 2.06
2	9	1.03	.29	.74 - 1.74
3	- -	- -	- -	- -
4	19	.92	.11	.74 - 1.17
5	23	1.03	.20	.69 - 1.49
6	- -	- -	- -	- -
7	1	1.41	- -	1.41 - 1.41
8	3	1.47	.17	1.28 - 1.59
9	1	3.22	- -	3.22 - 3.22
	Brackish Vegetative Type			
1	25	.83	.27	.53 - 1.93
2	16	.87	.15	.62 - 1.17
3	6	.94	.26	.70 - 1.42
4	21	.76	.21	.44 - 1.45
5	17	1.12	1.43	.48 - 6.63
6	- -	- -	- -	- -
7	18	1.12	.30	.50 - 1.69
8	12	1.12	.24	.79 - 1.54
9	21	1.37	.35	.78 - 2.10
	Intermediate Vegetative Type			
1	2	.63	.31	.40 - .85
2	1	.41	- -	.41 - .41
3	7	1.08	.53	.33 - 2.05
4	3	.37	.06	.30 - .43
5	4	.55	.14	.41 - .71
6	- -	- -	- -	- -
7	11	1.68	1.85	.47 - 7.12
8	8	1.45	.31	1.04 - 1.93
9	11	1.30	.72	.40 - 3.06
	Fresh Vegetative Type			
1	3	.35	.09	.29 - .46
2	- -	- -	- -	- -
3	9	.99	.25	.56 - 1.38
4	25	.22	.13	.03 - .54
5	28	.40	.46	.08 - 2.25
6	3	.42	.10	.30 - .50
7	6	.73	.35	.24 - 1.31
8	19	.66	.41	.20 - 1.51
9	3	1.04	.29	.75 - 1.35

Table 29. Sodium content (ppt) of marsh soils by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
Saline Vegetative Type				
1	15	4.50	1.87	.55 - 7.60
2	9	4.71	2.51	2.39 - 10.70
3	- -	- -	- -	- -
4	19	3.77	.76	2.54 - 5.05
5	23	4.75	1.48	2.47 - 7.74
6	- -	- -	- -	- -
7	1	4.22	- -	4.22 - 4.22
8	3	4.28	.61	3.70 - 4.93
9	1	2.55	- -	2.55 - 2.55
Brackish Vegetative Type				
1	25	3.22	.92	1.60 - 4.92
2	16	3.43	.86	1.72 - 4.90
3	6	2.24	1.31	.60 - 3.82
4	21	3.19	1.10	1.47 - 5.94
5	17	5.20	8.73	1.23 - 38.72
6	- -	- -	- -	- -
7	18	2.45	1.20	.37 - 5.15
8	12	3.04	1.26	.89 - 4.66
9	21	3.34	1.23	1.27 - 5.68
Intermediate Vegetative Type				
1	2	1.68	.28	1.48 - 1.88
2	1	1.46	- -	1.46 - 1.46
3	7	1.45	.99	.50 - 3.01
4	3	1.43	.12	1.31 - 1.56
5	4	1.53	.77	.49 - 2.18
6	- -	- -	- -	- -
7	11	.90	.43	.19 - 1.70
8	8	1.44	.56	.76 - 2.42
9	11	2.20	1.50	.42 - 5.88
Fresh Vegetative Type				
1	3	.82	.12	.71 - .95
2	- -	- -	- -	- -
3	9	.39	.20	.19 - .84
4	25	.64	.45	.02 - 1.49
5	28	.46	.63	.05 - 2.43
6	3	.18	.14	.06 - .35
7	6	.95	.94	.09 - 2.71
8	19	.51	.36	.07 - 1.31
9	3	1.00	.16	.81 - 1.10

Table 30. Soil reaction (pH) by hydrologic unit and vegetative type

Hydrologic Unit	No. of Samples	Mean	Standard Deviation	Range
	Saline Vegetative Type			
1	15	6.08	.80	4.80 - 7.80
2	9	6.27	.62	5.10 - 7.10
3	- -	- -	- -	- -
4	19	6.23	.59	4.90 - 7.20
5	23	6.18	.52	5.10 - 6.80
6	- -	- -	- -	- -
7	1	6.40	- -	6.40 - 6.40
8	3	6.56	.32	6.20 - 6.80
9	1	7.70	- -	7.70 - 7.70
	Brackish Vegetative Type			
1	25	5.45	.87	3.70 - 7.80
2	16	5.56	.92	4.00 - 6.90
3	6	5.86	.82	5.10 - 7.30
4	21	5.48	.58	4.40 - 6.40
5	17	5.47	.63	4.00 - 6.70
6	- -	- -	- -	- -
7	18	5.64	.42	4.80 - 6.50
8	12	6.09	.49	5.50 - 6.90
9	21	6.16	.36	5.20 - 6.80
	Intermediate Vegetative Type			
1	2	5.40	.56	5.00 - 5.80
2	1	3.80	- -	3.80 - 3.80
3	7	6.97	.90	5.80 - 8.10
4	3	5.57	.42	5.10 - 5.90
5	4	5.37	.29	5.00 - 5.70
6	- -	- -	- -	- -
7	11	5.73	.43	5.30 - 6.50
8	8	5.70	.37	5.10 - 6.10
9	11	5.78	.38	5.30 - 6.30
	Fresh Vegetative Type			
1	3	4.76	.23	4.50 - 4.90
2	- -	- -	- -	- -
3	9	6.61	.72	5.30 - 7.20
4	25	5.10	.42	4.10 - 5.90
5	28	5.24	.43	4.30 - 6.30
6	3	5.50	.45	5.00 - 5.90
7	6	5.15	.46	4.50 - 5.90
8	19	5.41	.37	4.50 - 6.00
9	3	5.60	.60	5.00 - 6.20

Table 31. Alphabetical listing of plants included in this study[a]

Scientific Name	Family	Common Name
Acnida alabamensis Standley	AMARANTHACEAE	Belle-dame
Aeschynomene virginica (L.) B.S.P.	LEGUMINOSAE	Sensitive jointvetch
Alternanthera philoxeroides Criseb.	AMARANTHACEAE	Alligator-weed
Aster sp.	COMPOSITAE	Aster
Avicennia nitida Jacq.	VERBENACEAE	Blackmangrove
Azolla caroliniana Willd.	SALVINIACEAE	Waterfern, Mosquitofe
Baccharis halimifolia L.	COMPOSITAE	Groundselbush, Buckbrush
Bacopa caroliniana (Walt.) Robins	SCROPHULARIACEAE	Carolina bacopa
Bacopa monnieri (L.) Pennell	SCROPHULARIACEAE	Waterhyssop
Bacopa rotundifolia (Michx.) Wettst.	SCROPHYLARIACEAE	Roundleaf bacopa
Batis maritima L.	BATIDACEAE	Batis
Bidens laevis (L.) B.S.P.	COMPOSITAE	Bur-marigold
Borrichia frutescens (L.) D. C.	COMPOSITAE	Sea-oxeye
Brasenia schreberi Gmel.	NYMPHAEACEAE	Watershield
Cabomba caroliniana Gray	NYMPHAEACEAE	Fanwort
Carex sp.	CYPERACEAE	Carex
Centella erecta (L.F.) Fern.	UMBELLIFERAE	
Cephalanthus occidentalis L.	RUBIACEAE	Buttonbush
Ceratophyllum demersum L.	CERATOPHYLLACEAE	Coontail
Cladium jamaicense Crantz.	CYPERACEAE	Sawgrass
Colocasia antiquorum	ARACEAE	Elephantsear
Cuscuta indecora Choisy	CONVOLVULACEAE	Dodder
Cynodon dactylon (L.) Pers.	GRAMINEAE	Bermuda grass
Cyperus compressus L.	CYPERACEAE	
Cyperus odoratus L.	CYPERACEAE	
Daubentonia texana Pierce	LEGUMINOSAE	Rattlebox
Decodon verticillatus (L.) Ell.	LYTHRACEAE	Water willow
Dichromena colorata (L.) Hitch.	CYPERACEAE	Star sedge
Distichlis spicata (L.) Greene	GRAMINEAE	Saltgrass
Dryopteris thelypteris var. Haliana (Fern.) Braun	POLYPODIACEAE	Southern marsh fern
Echinochloa walteri (Pursh) Ash	GRAMINEAE	Walter's millet
Eichornia crassipes (Mart.) Solms	PONTEDERIACEAE	Waterhyacinth
Eleocharis parvula (R. & S.) Link	CYPERACEAE	Dwarf spikerush
Eleocharis quadrangulata (Michx.) R. & S.	CYPERACEAE	Four square sedge
Eleocharis sp.	CYPERACEAE	Spikerush
Eupatorium capillifolium (Lam.) Small	COMPOSITAE	Yankee weed, Dogfenne
Eupatorium sp.	COMPOSITAE	Boneset
Fimbristylis castanea (Michx.) Vahl.	CYPERACEAE	
Gerardia maritima Raf.	SCROPHULARIACEAE	
Heliotropium curassavicum L.	BARAGINACEAE	Seaside heliotrope
Hibiscus lasiocarpus Car.	MALVACEAE	Rose mallow, Marsh ma
Hydrocotyle bonariensis Lam.	UMBELLIFERAE	
Hydrocotyle ranunculoides L. F.	UMBELLIFERAE	
Hydrocotyle umbellata L.	UMBELLIFERAE	Water pennywort
Hypericum virginicum L.	GUTTIFERAE	Marsh St. John's wort
Hymenocallis occidentalis (LeConte) Kunth	AMARYLLIDACEAE	Spiderlily
Ipomoea sagittata Cav.	CONVOLVULACEAE	Morning glory
Ipomoea stolonifera (Cyrill.) Poir.	CONVOLVULACEAE	Morning glory

(Continued)

le 31. (Continued)

entific Name	Family	Common Name
cus effusus L.	JUNCACEAE	Soft rush
cus roemerianus Scheele	JUNCACEAE	Black rush
siaea diffusa Forskl.	ONAGRACEAE	Water primrose
siaea sp.	ONOGRACEAE	Willow primrose
teletzkya virginica (L.) Roth	MALVACEAE	Pink hybiscus
na minor L.	LEMNACEAE	Duckweed
tochloa fascicularis (Lam.) A.	GRAMINEAE	Sprangletop
tochloa filiformis (Lam.) Beauv.	GRAMINEAE	Red sprangletop
nobium spongia (Bosc.) Steud.	HYDROCHARITACEAE	Frogbit
pia nodiflora (L.) Michx.	VERBENACEAE	
ium carolinianum Walt.	SOLANACEAE	Salt matrimonyvine
hrum lineare L.	LYTHRACEAE	Loosestrife
ica cerifera L.	MYRICACEAE	Wax myrtle
iophyllum heterophyllum Michx.	HALORAGACEAE	Variable watermilfoil
iophyllum spicatum L.	HALORAGACEAE	Eurasian watermilfoil
as quadalupensis (Spreng.) Mangus	NAJADACEAE	Southern naiad
umbo lutea (Willd.) Pers.	NYMPHAEACEAE	American lotus
phaea odorata Ait.	NYMPHAEACEAE	White waterlily
phaea tuberosa Paine	NYMPHAEACEAE	White waterlily
phoides aquaticum (Walt.) Ktze.	GENTIANACEAE	Floatingheart
unda regalis L.	OSMUNDACEAE	Royal fern
elia alismoides Pers.	HYDROCHARITACEAE	
icum hemitomon Schultes	GRAMINEAE	Maidencane, Paille fine
icum repens L.	GRAMINEAE	Dog tooth grass, Chen-dent
icum virgatum L.	GRAMINEAE	Feather grass
icum sp.	GRAMINEAE	
palum dissectum L.	GRAMINEAE	
palum viginatum Swartz.	GRAMINEAE	
loxerus vermicularis (L.) R. Br.	AMAEANTHACEAE	Salt alligatorweed
agmites communis Trin.	GRAMINEAE	Roseau
chea camphorata (L.) D. C.	COMPOSITAE	Camphorweed
chea foetida (L.) D. C.	COMPOSITAE	Stinking fleabane
ygonum sp.	POLYGONACEAE	Smartweed
tederia cordata L.	PONTEDERIACEAE	Pickerelweed
amogeton nodosus Poir.	ZOSTERACEAE	Longleaf pondweed
amogeton pusillus L.	ZOSTERACEAE	Slender pondweed
pia maritima L.	ZOSTERACEAE	Widgeongrass
ciolepsis striata (L.) Nash	GRAMINEAE	Bagscale
ittaria falcata Pursh	ALISMATACEAE	Bulltongue
ittaria latifolia Willd.	ALISMATACEAE	Wapato
ittaria platyphylla (Engelm.) J. G. Sm.	ALISMATACEAE	Delta duck potato
ittaria sp.	ALISMATACEAE	
icornia bigelovii Torr.	CHENOPODIACEAE	Glasswort
icornia virginica L.	CHENOPODIACEAE	Glasswort
ix nigra Marsh.	SALICACEAE	Black willow
rurus cernuus L.	SAURURACEAE	Lizzard's tail
rpus americanus Pers.	CYPERACEAE	Freshwater three-square
rpus californicus (C. A. Meyer) Britton	CYPERACEAE	Hardstem bulrush, Bullwhip
rpus olneyi Gray	CYPERACEAE	Three-cornered grass
rpus robustus Pursh	CYPERACEAE	Leafy three-square
rpus validus Vahl	CYPERACEAE	Soft stem bulrush
bania exaltata (Raf.) Cory	LEGUMINOSAE	

(Continued)

Table 31. (Continued)

Scientific Name	Family	Common Name
Sesuvium portulascastrum L.	AIZOACEAE	Marsh purslane
Setaria glauca (L.) Beauv.	GRAMINEAE	Yellow foxtail
Setaria magna Griseb.	GRAMINEAE	Giant foxtail
Solidago sp.	COMPOSITAE	Goldenrod
Spartina alterniflora Loisel.	GRAMINEAE	Oystergrass
Spartina cynosuroides (L.) Roth	GRAMINEAE	Hog cane
Spartina patens (Ait.) Muhl.	GRAMINEAE	Marshhay cordgrass, Wiregrass
Spartina spartineae (Trin.) Merr.	GRAMINEAE	
Spirodela polyrhiza (L.) Schleid	LEMNACEAE	Duckweed
Suaeda linearis (Ell.) Moq.	CHENOPODIACEAE	Sea-blite
Taraxacum officinale Weber	COMPOSITAE	Dandelion
Taxodium distichum (L.) Richard	PINACEAE	Baldcypress
Typha spp.	TYPHACEAE	Cattail
Utricularia cornuta Michx.	LENTIBULARIACEAE	Horned bladderwort
Utricularia subulata L.	LENTIBULARIACEAE	Zigzag bladderwort
Vallisneria americana Michx.	HYDROCHARITACEAE	Wildcelery
Vigna repens (L.) Kuntze	LEGUMINOSAE	Deer pea
Woodwardia virginica (L.) Sm.	POLYPODIACEAE	Virginia chain fern
Zizaniopsis miliaceae (Michx.) Doll & Aschers	GRAMINEAE	Giant cutgrass

[a] Plant names are from the following sources:

(1) Fernald (1950)
(2) Gleason (1968)
(3) Hitchcock (1950)
(4) Small (1933)

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The Distribution and Characteristics Of Farm Accidents In Louisiana

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Karen Paterson
Joe Novack
Alvin L. Bertrand

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The Distribution and Characteristics Of Farm Accidents in Louisiana

KAREN W. PATERSON, JOSEPH A. NOVACK
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Introduction

The ability of our decreasing farm population to produce sufficient food for the nation has been accomplished, in part, through technological advancements. Better soil utilization, more effective fertilizers, efficient and selective chemical treatment of plant and animal diseases, and increased mechanization of planting, harvesting, and other farming procedures, have all played their part in increasing the food-producing capability of United States farmers. The trend toward fewer but larger farms, fewer but more productive laborers, and a myriad of other factors have made agriculture a highly competitive and therefore expensive business, requiring large capital outlays.

Although agriculture has become a "big business" and has experienced an increasing mechanization of procedures, it does not have well developed safety standards as other industries do. Farm safety practices and procedures are, for the most part, of a hit-or-miss nature—a shortcoming evidenced by a comparatively high rate of accidents on farms. High risk occupations, such as those involved in highway construction and other types of heavy construction, not only have lower accident rates than farming, but their rates are exhibiting a downward trend.[1]

Objectives and Methodological Procedures

This study had an overall goal of determining the farm accident characteristics of farmers in Louisiana. Specific objectives were: (1) to provide up-to-date information on farm accidents for the use of safety planners at all levels, including such state- and federally-supported agencies as the Cooperative Extension Service, the Louisiana Agricultural Experiment Station (more specifically, the Agricultural Engineering Department), and manufacturers of farm equipment, machinery, and chemicals; (2) to provide a base for comparison of farm accidents in Louisiana with those in other states; (3) to contribute to the National Safety Council's program to standardize farm accident reporting procedures over the nation, and (4) to contribute to the overall programs of the state and nation to improve the well-being of citizens.

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[1] *Handbook of Labor Statistics* 1969, Bureau of Labor Statistics Bulletin No. 1630, and Metropolitan Life *Statistical Bulletin*, Vol. 51, July 1970, p. 8.

Twenty-five of Louisiana's 64 parishes, chosen at random, comprised the sample frame for this survey. These parishes were located in six types of farming areas delineated within the state through the use of political boundaries (parishes). While this procedure may raise questions regarding homogeneity, it is a relatively effective method of reflecting the gross characteristics of land-type and land-use in one state. The sampling unit was the individual farm, represented by the head of the farm household. A final sample of 1,561 was obtained from the parishes listed.[2]

The following are the six types of farming areas and the sample parishes used to represent each.

1. Timber, hill, cutover pine and flatwood area—Beauregard, Bienville, Sabine, Vernon.
2. Red River and Mississippi Delta area—Caddo, Caldwell, Madison, Rapides, Red River, West Carroll.
3. Central Louisiana mixed farming area—Evangeline, Lafayette, St. Landry.
4. Rice area—Acadia, Allen, Cameron, Calcasieu, Vermilion.
5. Sugarcane area—Iberia, Lafourche, St. John, St. James, St. Mary.
6. Dairy, poultry and truck area, and New Orleans truck and fruit area—Livingston, Washington.

Figure 1 shows the location of the six farming areas and the sample parishes.

Two key definitions were employed in this study at the request of the National Safety Council: (1) a **farm** was defined as a place where $250 or more in agricultural products were sold annually or a place where at least $50 or more in agricultural products were sold annually and the size of the holding was 10 or more acres; (2) an **accident** was defined as injury to any person living or working on a farm, or a visitor who was injured while visiting the farm, that required professional medical care or the loss of one-half day or more from usual activities (work, school, play, etc.). These definitions were incorporated in the survey questionnaire.

The questionnaire was designed to enable non-professional interviewers to use it successfully. This was necessary since members of parish Home Demonstration Clubs voluntarily served as interviewers. The results obtained were judged good and in keeping with the research objectives.

Four separate interview forms were employed. The individual forms were color-coded for the benefit of interviewers. The first form was

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[2] Through the use of accepted sample-size determination techniques, it was determined that a simple random sample of 1,100 farms would allow a 98 percent confidence that the true percentage of farm accidents in the total population would be within 2.5 percent of the values obtained in the study.

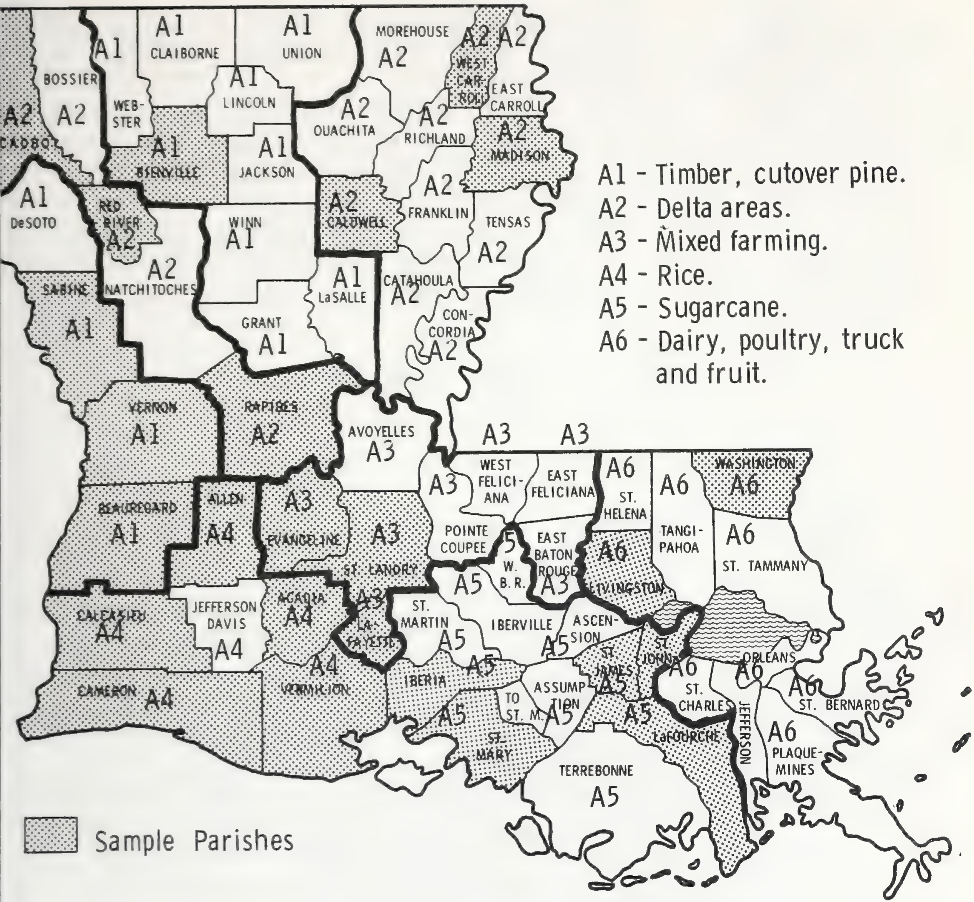

FIGURE 1.—Louisiana parishes in the sample frame.

designed to produce demographic, economic, and attitudinal data on the farm owner, his family, and his employees. It was administered only once—at the beginning of the survey. Subsequent interview sessions conducted at three-month intervals were concerned only with accident data. The second form, the accident report form, was used to gather data on all accidents regardless of type. In addition to the general accident form, two supplemental accident forms were made available. Both are quite short and were designed to collect information on two specific types of accidents—those involving either tractors or one of seven types of chemicals.

The item format in all four forms was predominantly of the forced-choice or check-block type. Open-end questions were used only where absolutely necessary in an attempt to keep the information reporting as uniform as possible throughout the state. The more than 250 interviewers involved in the study reported little difficulty in administering the research instruments.

Interviewer training was accomplished by teams composed of members of the on-campus co-sponsors of the project. The actual training sessions held by the several professional teams took place in central locations in sample-frame parishes. In at least half of these training sessions two or more Home Demonstration Clubs were represented. The training period lasted approximately six weeks beginning in early March, 1970. The time span of the survey was from January 1, 1970 to December 31, 1970.

Conceptual Frame of Reference

The conceptual framework which provided a methodological orientation for this research can be identified as the epidemiological approach. This approach has been successfully implemented in previous studies of specific types of accidents.[3]

Epidemiology is a method of investigation developed in the field of medicine, originally, as a means of logical research on the prevalence and incidence of infectious diseases. In its "mother field" it has become, over the years, an area of specialization in its own right. Public health agencies were quick to realize its potential uses in the development of preventive-measures programs concerned with disease. Its wide currency as an accepted research method in disease etiology led to its application to non-disease health problems, such as accidents. Although its use is still predominantly disease-research oriented, its use has been successful enough in the study of accidents to permit one writer to state:

> . . . accidents exhibit some of the same biological and physical inter-relationships as do disease processes . . . when . . . analyzed in a standard epidemiological manner it has been shown that accident distributions, like disease, show characteristic variations.[4]

Another writer observes that " . . . all human blights and injuries have their epidemiology. . . ."[5]

Most epidemiological writings stress the importance of the interrelationships of three factors: (1) a host; (2) an agent, and (3) an environment.[6] Also of importance to the correct utilization of this method

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[3] Ross A. McFarland, "The Epidemiology of Motor Vehicle Accidents," in Alfred H. Katz and Jean Spencer Felton, *Health and the Community* (New York: The Free Press, 1965).

[4] *Ibid., p. 76.*

[5] John R. Paul, *Clinical Epidemiology* (Chicago: The University of Chicago Press, 1966), p. 4.

[6] See Ivan Ivanovitch Elkins (ed), *A Course in Epidemiology* (London: Pergamon Press, 1961). Translated from the Russian. This volume contains a discussion of general epidemiology by the editor, and a selection of special epidemiology studies. I. N. Morris, *Uses of Epidemiology* (Edinburgh and London: E & S Livingstone, 1957), also stresses this point and includes a historical development sketch of epidemiology.

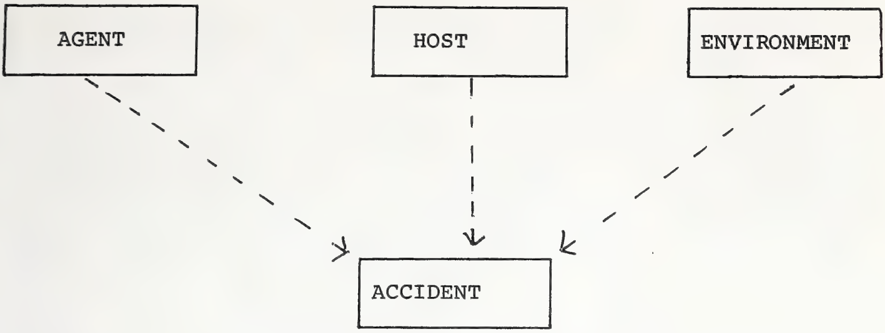

FIGURE 2.—Basic epidemiological conceptual model of accidents.

is the awareness that the object of study is not an individual, but groups of individuals with some common life experiences.

The host in accident epidemiology is the *person*, or *persons*, involved in a specific accident. The agent in accident epidemiology is the *thing* involved in the accident—it may be a tractor, a ladder, a power tool, etc. The environment in accident epidemiology can be broadly dichotomized into the *physical* and the *social*. Physical environment is composed of the various climatological and topographical characteristics of the hosts' areal location. Social environment includes such items as family size, education, group identification, etc.—all the forces that are generally recognized as being part of the socialization process.

Figure 2 is a graphic presentation of components involved in the basic epidemiological conceptual model of accidents. All relevant variables associated with accident occurrence are subsumed under one or more of the component parts. In any given accident all three components are represented.

The combination of a viable agent, a susceptible host, and a predisposing environment are the basic requirements of an accident situation, or possible accident situation. Three "types" of factors, used to infer causal or associational relationships, intervene between the agent-host-environment components and the accident to complete the conceptual model. Figure 3 contains these intervening factor-types in a representation of the conceptual model employed in this research.

This research conceptual model is a modification of a model utilized by Mellinger and Manheimer.[7] The intervening factors in their study

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[7] Glen Mellinger and Dean Manheimer, "An Exposure Coping Model of Accident Liability Among Children," *Journal of Health and Social Behavior*, Vol. 8, No. 2, June, 1967, p. 96. Some of the modifications used were inspired by Saxon Graham, "Social Factors in the Epidemiology of Cancer at Various Sites," *Annals of the New York Academy of Sciences*, Vol. 84, article 17, December 8, 1960.

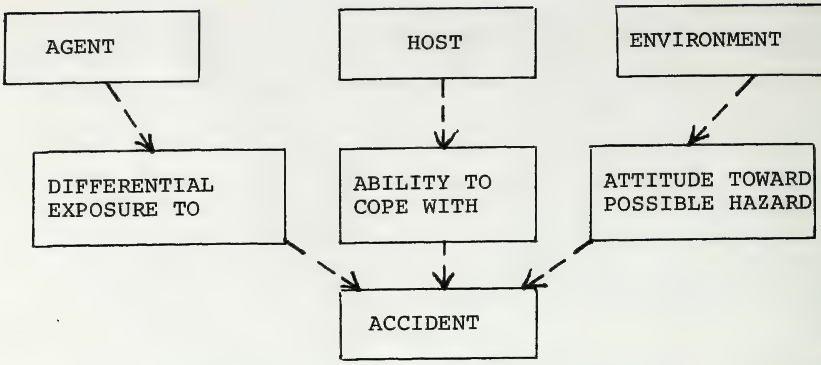

FIGURE 3.—The research conceptual model.

are: (1) exposure to hazard; (2) ability to cope with hazard, and (3) personality maladjustment.[8] In this research "personality maladjustment" has been replaced by "attitude toward possible hazard" because no attempt has been made to gather personality data and because the more specifically delimited area of hazard attitudes is germane to the research problem under investigation.

The specific variables deemed to comprise the "factor-types" included the following:

Differential exposure to hazard—(1) hours per week spent in actual farm work; (2) number of acres farmed; (3) amount and types of equipment; (4) geographical location of farm among six areas in the state; (5) sex.

Ability to cope with hazard—(1) number of years of farm work experience; (2) educational attainment; (3) safety training in other occupations; (4) age.

Attitude toward possible hazard—(1) concern with proper equipment-operation training; (2) concern with safety conditions of buildings, inadequate wiring, etc.; (3) concern with safe work regulations, such as prohibition of smoking in barns and fuel storage areas, storage of fuels, etc.; (4) concern with safety plans, such as family fire plans, etc.; (5) provision of chemical antidotes, first-aid kits, and related items.

The three factor-types and the variables assigned to them are not mutually exclusive. For example, a concern with proper equipment operation could conceivably affect the ability to cope with hazards; age could be logically felt to affect the differential exposure to hazard. Indeed, the interrelationships of the variables between and within the factor-types were of central concern in the research.

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[8] *Op. cit.*, Mellinger and Manheimer, p. 96.

Characteristics of Farm Accidents in Louisiana

Number and Severity of Accidents

One hundred eighty-two accidents were reported to have occurred from January 1, 1970 to December 31, 1970 on the farms in the sample population studied. Of these, 32 percent were reported in Area 4 (rice area). Area 2 (Red River and Mississippi Delta area) had the next highest occurrence, accounting for 24 percent of all accidents reported. The sugarcane area (Area 5) accounted for 17 percent of the farm accidents in the sample population. Thus, the combination of the rice, cotton, and sugarcane areas of the state accounted for 73 percent of the accidents reported during the 12-month survey.

The same three areas (Areas 4, 2 and 5) also experienced the highest frequencies of farm accidents in all severity categories (Table 1). Accidents were classified according to the seriousness of the injury: (1) a fatal accident; (2) a permanent injury, referring to loss of an eye or limb, paralysis, or other disability which permanently restricted activities; (3) a severe injury, including such things as a broken leg, cut ligament, or sprained back, and (4) a slight injury, such as minor cuts, sprains, burns, or bruises.

The number of restricted activity days associated with a severe injury varies, of course. However, the national average from 1965 to 1967 was about two weeks. By contrast, the average number of days of restricted activity for slight injuries was about four days.

It can be seen in Table 1 that the great preponderance of all farm accidents reported fell in the "slight" category, i.e., they involved such injuries as minor cuts, bruises, abrasions, etc. These injuries accounted for seven out of 10 (71 percent) of all injuries reported. It should be remembered, however, that for an accident to be reported at all it must have required professional medical assistance or caused the loss of at least one-half day of normal activity. Under these criteria

TABLE 1.—Number of Farm Accidents in the Six Land-Type, Crop-Usage Areas by Seriousness of Injury

Type farming area	Seriousness of injury								
	Fatal		Permanent		Severe		Slight		Total
	No.	%	No.	%	No.	%	No.	%	
Area 1—Timber	0	(0)	1	(33)	4	(9)	15	(12)	20
Area 2—Delta and Red River	1	(50)	0	(0)	11	(24)	31	(24)	43
Area 3—Mixed farming	0	(0)	0	(0)	6	(14)	12	(9)	18
Area 4—Rice	1	(50)	1	(33)	16	(34)	40	(31)	58
Area 5—Sugarcane	0	(0)	0	(0)	7	(12)	25	(19)	32
Area 6—Dairy and truck farms	0	(0)	1	(33)	3	(7)	7	(5)	11
Total	2	(100)	3	(100)	47	(100)	130	(100)	182

even "slight" injuries are important from the standpoint of personal discomfort and suffering as well as from an economic standpoint.

The more serious injuries, as one would expect, occurred less frequently than minor injuries. Nevertheless, such injuries as a broken leg or sprained back made up over one-fourth (26 percent) of the injuries reported. It is most encouraging that only about two percent of all injuries were permanent and only one percent resulted in a fatality.

The distribution of accidents by severity class was not unanticipated. The percentage distribution of farm accidents by seriousness of injury was much the same in a similar study done earlier in Michigan. In the Michigan study, 66 percent of all injuries were considered slight injuries, 30 percent were judged severe, four percent were classed as permanent, and one percent were recorded as fatal.

Work Conditions Under Which Accidents Occurred

Approximately 59 percent of all farm accidents reported in this study occurred while the individual involved was performing farm work (farm-related activities such as tilling, plowing, harvesting, milking, or repair jobs). The remainder of the accidents did not involve farm work directly, although the activity usually was common around farms.

When males and females involved in accidents were compared, it was found that the sexes were almost diametrically opposed in the work conditions under which their accidents occurred. Sixty-five percent of all accidents involving males occurred while the individual was performing farm work; by contrast, 69 percent of all accidents involving females occurred while the individual was engaged in non-farm work. These differences are accounted for in terms of the work roles of men and women. The latter are less likely to be exposed to the more demanding farm jobs.

The effects of exposure to specific hazards are evidenced in the distribution of accidents according to the machine or other factor involved (Table 2). The percentage of men suffering farm accidents involving machinery was nearly twice as high as the percentage of females having accidents with farm machinery. This, of course, was not unexpected in

TABLE 2.—Factors Contributing to Farm Accidents by Sex of Respondents*

Factor	Male		Female		
	No.	%	No.	%	Total
Power tool	11	(8)	5	(14)	16
Hand tool	11	(8)	0	(0)	11
Farm machinery	48	(33)	6	(17)	54
General item	59	(40)	21	(58)	80
Animal	17	(11)	4	(11)	21
Total	146	(100)	36	(100)	182

*Percentages are within sex categories.

that men use farm machinery more frequently. However, it is interesting that women had a higher percentage of power tool accidents than men. This may indicate a lack of skill in handling drills, saws, etc.

Men and women were both highly susceptible to "general item" accidents, although here again women predominated—40 percent of the accidents for males and 58 percent for females were of this type. The classification "general item" is a broad one as used here and this accounts in part for the high incident rate in that category. The majority of slips and falls and of accidents occurring in the home which did not involve characteristics suitable for other classifications were included as "general" in nature. Approximately four out of 10 incidents in the "general item" classification were slips and falls.

Place Where Accidents Occurred

Farm fields, homeyards, and barnyards proved to be the most likely places for accidents in the farm complex of Louisiana. Nearly 60 percent (59.8 percent) of all accidents recorded during the course of the field work occurred in one of these three locations (Figure 4).

The high number of field accidents (55) is in accordance with the high number of farm machinery accidents reported and presented in

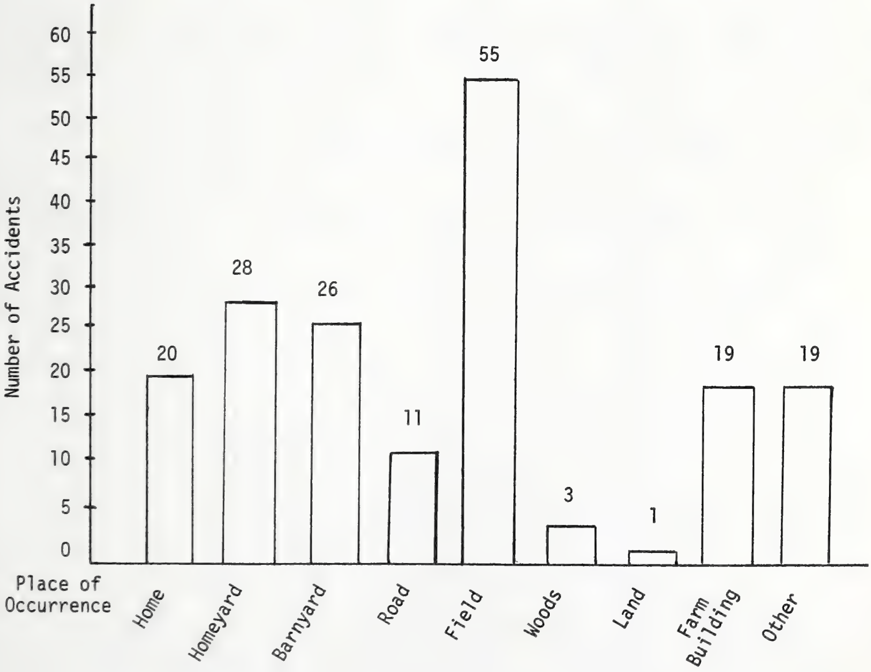

FIGURE 4.—Distribution of farm accidents by place of occurrence.

Table 2. Accidents in barnyards, where most farm machinery is also operated, accounted for 14 percent of all reported accidents. Many accidents occurred near the home and farm buildings. The homeyard was the scene of 15 percent of the accidents, while 11 percent of the accidents occurred in the home itself and about 10 percent in farm buildings.

Type of Injuries Sustained in Accidents

It was found that the parts of the body most frequently injured in farm accidents were the leg, the head, and the foot. Figure 5 shows the distribution of accidents by the part of the body injured.

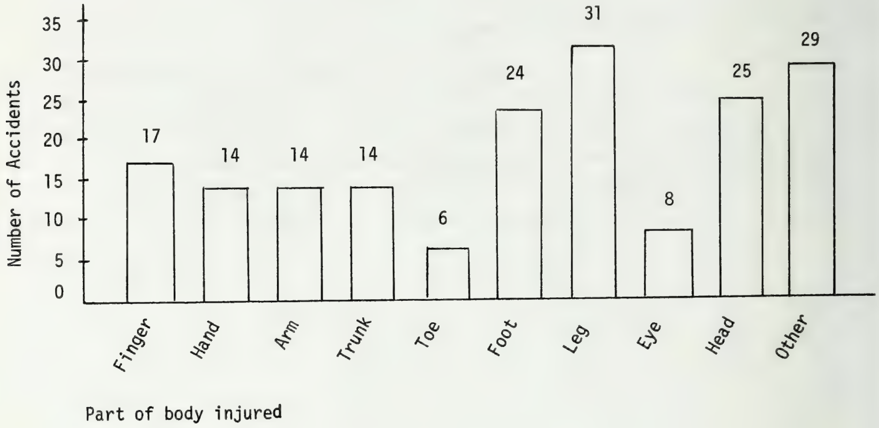

FIGURE 5.—Distribution of farm accidents by part of body injured.

Thirty-one of the 182 accidents reported involved an injury to the leg; 25 involved an injury to the head, and 24 an injury to the foot. It can be seen in Figure 5 that finger, hand, arm, and trunk accidents were also quite common. Toe and eye accidents occurred less frequently, but often enough to suggest safety precautions. The "other" category in Figure 5 is composed primarily of accidents that affected two or more parts of the body, and/or could not readily be considered as belonging in one of the other nine classifications.

The Farm Accident Rate in Louisiana

A rate is simply a ratio of the number of events of interest, accidents in this case, to an estimate of the population exposed to the risk of experiencing that event. This study was designed to collect data needed for calculation of accident rates. The population "at risk"—essentially members of farm families, other farm residents, and farm workers—was counted in the first interview, which was described in the section on methodological procedures. Accident frequencies were then obtained from the subsequent quarterly reports.

Accident rates were calculated (1) according to a person's relationship to the farm operator, and (2) according to whether or not the person worked on a farm. The guiding assumption was that different roles on the farm involve different kinds of exposures to the risk of accidents within the general farm environment. For some persons the farm is primarily a workplace, but for wives it may well be more the site of living space including a kitchen, etc., and for children it may be a playground in addition to a place to eat and sleep.

Accident rates for persons grouped by their relationship to the farm operator and by their farm employment status are shown in Table 3, where rates are expressed as the number of accidents per 1,000 persons in the appropriate group. Two aspects of this table should be held in mind. First, statistical tests of significance have not been pursued because it was felt that, given the accident frequency and sample size, there was a greater danger of rejecting substantively interesting differences than of accepting as important those differences that might be simply due to sampling error. As studies of this kind accumulate and comparisons can be made between studies the question of statistical significance in any one study becomes much less important. However, it should be recognized that a rather low number of accidents, 182, is involved and because of this the rates for particular groups might be

TABLE 3.—Accident Rates by Relationship of Farm Population to Farm Operator and Farm Employment Status

Relationship to farm operator Farm employment status	Farm population	Number of accidents reported	Accident rate per 1,000 population
Farm operator	1,561	47	30
All wives	1,275	18	14
Wives working on farm	437	13	30
Wives not working on farm	838	5	6
All sons	1,100	43	39
Sons working on farm	575	29	50
Sons not working on farm	525	14	27
All daughters	824	10	12
Daughters working on farm	232	5	22
Daughters not working on farm	592	5	8
Other relatives**	277	4	14
Other farm residents not related to farm operator**	81	4	49
Total farm residents	5,118	126	25
Unrelated farm workers*	(396)	56	—

*Calculation of rates inappropriate—see text, p. 16.

**The number of accidents was not sufficiently large to further subdivide rates by whether or not the person worked on the farm.

somewhat unstable and likely to vary a little from year to year.

Secondly, the procedure followed in collecting data for the calculation of rates worked well for members of the farm family, but not for farm workers. The population counted in the initial interview included those farm workers on the farm at that date, but many accidents occurred to temporary workers later in the year and no count was made of this shifting population. A relatively large number of accidents, 56 of 182, occurred to farm workers and it is probable that the rate of accidents was high for that group, but the rate cannot be precisely calculated because the population at risk cannot be estimated closely.

If accidents to workers are excluded, there was an overall accident rate of 25 per 1,000 persons (Table 3). Farm operators exceeded the average with a rate of 30 per 1,000. On the other hand, the accident rate for wives varied greatly according to whether or not they worked on the farm. Those wives working on the farm had an accident rate equal to that of the farm operators. Those not engaged in farm work had an extremely low accident rate of only six per 1,000. The same kind of difference was evident for sons and daughters within the farm family. Sons had a very high rate of accidents compared with that of daughters, and within each group those who worked on the farm had much higher accident rates than those who did not work on the farm. The high accident rate for farm-working sons is approached only by the miscellaneous group of other farm residents, not family members. Other family members, mainly parents of the farm operator and grandchildren, had a low accident rate.

The pattern of accident rates shown in Table 3 suggests the importance of recognizing variations in the farm environment. It is evident that the farm as a workplace involves quite different and greater risks from those arising in the course of its use as a mere residence. Similarly it is evident that children are exposed rather differently to farm work by sex. The large difference in rates when sons and daughters are compared suggests that sons are involved in work tasks not assigned to daughters. However, the large difference between children not involved in farm work implies an even broader differentiation in exposure to accidents by roles associated with sex.

This division of the sample by relationship to the farm operator and farm employment status also results in differences by age, educational attainment and work experience. The very low numbers of accidents experienced by some of the groups prevent more detailed analysis by such characteristics as age and education. Daughters, wives not working on the farm, other relatives, and other residents, all had very low accident frequencies. Consequently, more detailed description of characteristics is confined to the farm operators, sons, and farm-working wives.

Socioeconomic Characteristics Related to Farm Accident Rates

Farm Operators: Accident Rates by Age, Education, and Exposure to Farming

It would be desirable to calculate all accident rates involving farm work in terms of relative exposure to farming (or number of hours spent in farm work over the year of the study). For example, it is probable that the fewer accidents to grandparents reflect in part the fewer hours spent by them in farming, as compared with farm operators. However, with the data available, the effect of exposure can be assessed only for farm operators.

There were 1,561 farm operators in the sample and this group suffered 47 accidents during the year under study. One hundred of these farm operators were female and they experienced three of the 47 accidents. The farm operators were a varied group in terms of exposure to farming. Five hundred sixty-two of the operators worked outside agriculture, as well as in farming, and had an accident rate of 27 per 1,000. The 999 operators who worked only on the farm had a higher rate, 32 per 1,000 (Table 4). It is also evident, in Table 4, that for each farm operator group the accident rate increases with the extent of exposure to farm work. For operators involved only in farming, the rate rises from 17 per 1,000 for less than 2,000 hours spent in agriculture over a year, to 51 per 1,000 for over 3,000 hours devoted to farming activity. A similar increase is apparent for farm operators who hold a job outside farming. However, having two or more occupa-

TABLE 4.—Accident Rates for Farm Operators by Exposure to Farming

Hours spent per year at farming	Sample population	Number of accidents reported	Accident rate per 1,000 population*
Farm operators working only in farming			
0-1,999	349	6	17
2,000-2,999	356	11	31
3,000 or more	294	15	51
0-1,999	349	6	17
2,000 or more	650	26	40
Total	999	32	32
Farm operators also working outside of farming			
0-999	339	6	18
1,000-1,999	145	5	34
2,000 or more	78	4	51
0-1,999	484	11	23
2,000 or more	78	4	51
Total	562	15	27

*Rates calculated with non-responses distributed over categories.

tions is associated with a considerably higher accident rate in terms of farm work exposure. For those farmers working outside agriculture fewer hours of farming are needed to accumulate an accident rate equivalent to that of full-time farmers. Thus, overall, those who work outside farming have a lower average accident rate than the group of operators who work only in agriculture. Yet, when the degree of exposure to farming is taken into account, the full-time farmers have the lowest rates among the farming classes.

Accidents to farm operators follow a distinct pattern according to age (Table 5). The youngest operators, those aged 19 to 29 years, have a very high rate of 56 per 1,000. The accident rate then drops to only 19 per 1,000 at ages 50 to 59, before climbing steeply again in the group aged over 60 years. It is not feasible to examine more than one variable at a time here, but the apparent impact of old age (beyond 60 years) on the accident rate is undoubtedly understated as the time actually spent on farming begins to decline at this age.

It was hypothesized before the data were collected that educational attainment would be negatively associated with accidents. That is, it was thought those with more education would experience fewer accidents, reflecting a greater awareness of hazards. The opposite was found to be true for farm operators (Table 6). The accident rate increased with schooling. Why this was true is subject to speculation. It may be related to variables such as exposure or age.

TABLE 5.—Accident Rates for All Farm Operators by Age

Age	Sample population	Number of accidents reported	Accident rate per 1,000 population
19-29	71	4	56
30-39	219	9	41
40-49	352	9	26
50-59	465	9	19
60 or more	454	16	35
Total	1,561	47	30

TABLE 6.—Accident Rates for All Farm Operators by Educational Attainment

Years of schooling	Sample population	Number of accidents reported	Accident rate per 1,000 population*
Less than attendance at high school (0-8)	633	16	25
Some high school (9-11)	416	13	31
High school graduate	316	11	35
More than high school attendance (13 or over)	196	7	36
Total	1,561	47	30

*Rates calculated with non-responses distributed over categories.

Farm-Working Wives: Accident Rates by Age, Education, and Hours Per Week Spent in Farming

The characteristics of wives working on the farm are displayed in Table 7. These wives had an accident rate lower than that of farm operators at all ages up to age 59. For those wives still working beyond age 60, the accident rate was extremely high—more than twice that of farm operators of the same age. Educational attainment had the expected relationship to accidents among wives, with the accident rate decreasing with additional years of schooling. More surprisingly, the number of hours worked in farming in an average week made no difference in the accident experience of wives. The hours worked per average week cannot be cumulated into hours per year exposure because the number of weeks worked was not ascertained except for farm operators.

TABLE 7.—Accident Rates for Wives Working on Farm by Age, Education, and Hours Spent at Farming per Week

Item	Sample population	Number of accidents reported	Accident rate per 1,000 population*
Age			
20-59	366	6	16
60 or more	71	7	99
Total	437	13	30
Education			
Less than high school attendance (0-8)	124	6	48
Some high school or more (9 or more)	313	7	22
Total	437	13	30
Hours spent at farming in an average week			
1-39	235	7	30
40 or more	202	6	30
Total	437	13	30

*Rates calculated with non-responses distributed over categories.

Sons: Accident Rates by Age and Hours Per Week in Farming

Among farm-working sons the relationship of age to accidents follows a U-shaped pattern similar to that for farm operators (Table 8). An extremely high rate of accident occurrence is observed among the 0-9 age group, although it should be noted that this rate is based on quite small numbers. The rate then drops sharply before climbing to relatively high levels at ages beyond 30 years.

Among farmer's sons, the pattern of accidents by age is strongly

TABLE 8.—Accident Rates for Sons Working on Farm by Age and Hours Spent at Farming per Week

Item	Sample population	Number of accidents reported	Accident rate per 1,000 population*
Age			
0-9	20	5	250
10-19	405	14	35
20-29	109	5	46
30 or more	41	5	122
Total	575	29	50
Hours spent at farming in an average week			
1-9	123	11	89
10-19	171	4	23
20-39	146	4	27
40-59	95	7	74
60 or more	40	3	75
Total	575	29	50

*Rates calculated with non-responses distributed over categories.

interrelated with the number of hours worked in an average week. As for other family members, very high rates are apparent among sons with the lowest number of hours of work exposure (0 to 9), followed by a considerable drop at 10 to 39 hours of exposure and an eventual rise at 40 to 60 hours of work per week.

The very high variation among accident rates for sons reflects the interaction of age and hours worked per week. Those in the youngest ages and with the least experience in farming were prone to high accident rates. Those aged 10 to 29 had lower accident rates because they had a preponderance of low and part-time exposure. At the same time, they were old enough and experienced enough to avoid the hazards of earlier ages. At age 30 and older, accident rates increased, partly because at these ages exposure to farming increased rapidly.

The relation of education to accidents among farmer's sons was not computed because of the difficulty of comparing sons at younger ages with minimal education with those sons who had completed or essentially completed their education.

Summary and Implications

This study of farm accidents was inspired by the fact that accidents represent one of the most important problems related to rural life and farming. Information on accidents was obtained from a survey of farms in 25 of Louisiana's 64 parishes. These parishes, chosen at random, reflect the various characteristics of land-type and land-use found throughout the state. A sample of 1,561 farms from the 25 parishes were monitored for accidents over a period of one year. Analysis of the data obtained determined that:

1. One hundred eighty-two accidents occurred in 1970 on the farms in the sample population. This was an average of one accident for every nine farms.

2. Seven out of 10 accidents reported involved such injuries as cuts and bruises. Only those instances where the victim lost at least a half-day's work or had to see a doctor were counted as accidents.

3. The majority of farm accidents reported (59 percent) occurred while the individual involved was performing farm work.

4. Interestingly, 80 percent of the accidents involved such things as slips, falls, and accidents of a general nature. The high percentage of the latter implies that although farm machinery safety programs are essential, general safety programs are also important and needed.

5. As might be expected, most accidents (three-fifths) occurred in farm fields, homeyards, and barnyards.

6. Interestingly, the most frequent injuries sustained in accidents were to the leg, head, and foot.

7. Thirty-one percent of all accidents over the year occurred to farm workers. Although the accident rate for this group is apparently very high, the rate cannot be accurately calculated due to the temporary and seasonal nature of the employment of this population subgroup.

8. The overall rate of accidents for the population was 25 per 1,000, excluding workers. Farm operators had a higher rate—30 per 1,000—than the average for all family members. Wives working on the farm had the same accident rate as farm operators, while wives not working on the farm had a very low rate of accidents, six per 1,000. Sons had accident rates higher than the average for all family members, ranging from 50 per 1,000 if they worked on the farm to 27 per 1,000 if they did not. Daughters generally experienced low rates of accidents, especially if they did not work on the farm.

9. Farm operators experienced 26 percent of all the accidents reported. The accident rate for farmers increased with the number of hours of exposure to farming. This increase also characterized those farmers who held jobs outside agriculture. This latter group experienced a high accident rate in relation to the number of hours they spent in farming. The accident rate for farm operators was highest during the younger and older ages. The accident rate also increased with education among this group.

10. Farm wives, up to age 59, had accident rates lower than those experienced by farm operators. Interestingly, wives working beyond age 60 experienced extremely high accident rates. However, the accident rate of wives decreased with an increase in their education.

11. Sons exhibited patterns similar to farm operators in that they experienced high accident rates at younger and older ages.

The above findings lead to some rather interesting conclusions. For one thing, it is clear that work on the farm is closely related to accidents. This is true regardless of family status, sex or education. Although there is nothing startling in this discovery, it does indicate the need for careful study of the safety practices and habits of persons working on farms, with the purpose in mind of devising more effective safety programs.

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Louisiana Soybean Variety Trials 1968-1971

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Louisiana Soybean Variety Trials, 1968-1971

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INTRODUCTION

Louisiana farmers harvested an estimated 37,812,000 bushels of soybeans in 1971 from 1,644,000 acres (Louisiana Crop and Livestock Reporting Service estimates). This compares with 4,728,000 bushels from 240,000 acres in 1961. Soybeans ranked second only to cattle and calves in cash farm sales in the state in 1971. More acres were planted to soybeans in Louisiana in 1971 than the combined acreage of cotton, corn, rice, sugarcane, and sorghum.

With the growing importance of soybeans in the state, it is essential that variety trials be conducted at several locations to aid farmers in selecting varieties best adapted to their area. Soybean variety tests have been conducted at various locations in Louisiana for a number of years. Results from these tests are published in the annual reports of the individual stations. In 1966, Dr. C. G. Shepherd initiated a uniform soybean variety testing program in Louisiana. Results from these tests have been published annually in the Research Report series by the Agronomy Department of the Louisiana Agricultural Experiment Station.

Because varieties do not always respond alike in yield and other characters when grown in different locations and years, it is desirable to combine the individual tests for analysis. The primary purpose of this report is to provide data on the relative performance of soybean varieties grown in Louisiana and to make recommendations based on these findings. Results reported here are from Alexandria, Baton Rouge, Bossier City, Crowley, St. Joseph, and Winnsboro.

METHODS

All soybean varieties grown on a significant acreage in Louisiana are entered in the trials each year. A variety is dropped when the acreage becomes insignificant. New varieties are included in the tests as soon as seed is available.

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Production practices such as rate and date of seeding, row spacing, weed and insect control, and combine harvesting conform closely to recommended practices for a given area. The pertinent cultural data and soil type for each test location are presented in Table 1.

Yields were based on combine-run samples at most locations in most years. An exception was at Baton Rouge, where yields were based on cleaned seed of 13% moisture. Yields per acre are reported as 60 pounds per bushel.

Plant height was determined as the average length of plants in a plot from the ground to the top extremity at maturity.

Maturity was taken as the date when the pods were dry and most of the leaves had fallen. Usually the stems were dry also.

Table 1.—Plot size, fertilizer treatment, and soil type at the commercial soybean variety test sites by years

Location	Number rows planted	Number rows harvested	Row length, ft.	Row width, in.	Fertilizer applied	Soil[1] type
			—1968—			
Alexandria	4	2	115	40	none	Nr sl lm
Baton Rouge	4	2	100	42	0-60-60	Ol sl lm
Bossier City	4	2	100	40	none	Nr sl lm
Crowley	6	4	80	32	0-60-30	Cr sl lm
St. Joseph	4	4	114	40	12-48-48	Co sl lm
Winnsboro	4	4	90	40	12-48-48	Lo sl lm
			—1969—			
Alexandria	4	2	80	40	none	Nr sl lm
Baton Rouge	4	2	100	42	0-60-60	Ol sl lm
Bossier City	4	2	100	40	none	Nr sl lm
Crowley	6	4	70	32	0-60-30	Cr sl lm
St. Joseph	4	4	114	40	12-48-48	Co sl lm
Winnsboro	4	2	60	40	15-60-60	Lo sl lm
			—1970—			
Alexandria	4	2	75	40	none	Nr sl lm
Baton Rouge	4	2	100	42	0-100-100	Ol sl lm
Bossier City	4	2	100	40	none	Nr sl lm
Crowley	6	4	75	32	0-60-30	Cr sl lm
St. Joseph	4	4	114	40	0-25-25	Co sl lm
Winnsboro	4	2	50	40	0-60-60	Ca sl lm
			—1971—			
Alexandria	4	2	89	40	none	Nr sl lm
Baton Rouge	4	2	100	40	16-48-48	Ol sl lm
Bossier City	4	2	100	40	none	Nr sl lm
Crowley	6	4	75	32	0-60-60	Cr sl lm
St. Joseph	4	4	131	40	17-52-52	Co sl lm
Winnsboro	4	2	50	40	0-60-60	Ca sl lm

[1] Nr = Norwood; Ol = Oliver; Cr = Crowley; Co = Commerce; Lo = Loring; and Ca = Calloway; sl lm = silt loam.

Lodging was recorded on a scale of 1 to 5 according to the following criteria:

1—almost all plants erect

2—either all plants leaning slightly, or a few plants down

3—either all plants leaning moderately, or 25 to 50% of the plants down

4—either all plants leaning considerably, or 50 to 80% of the plants down

5—all plants down.

Shattering notes were taken on the border rows, except at St. Joseph, 14 days after maturity. The estimates were recorded on a scale of 1 to 5 as follows:

1—no shattering

2—1 to 3% shattered

3—4 to 8% shattered

4—9 to 19% shattered

5—over 20% shattered.

Height of lower pods was recorded as the average height of lowest pods from the ground.

Variety descriptive traits and reaction to the major soybean pests in Louisiana are shown in Table 2.

STATISTICAL ANALYSIS

Individual tests at each location were arranged in a randomized complete block, usually with four replications. Yield data from each location for each year were statistically analyzed. Fifteen or 16 varieties were included in the tests for a given year, but 12 varieties were tested at all six locations in each of the four years. Data from these 12 varieties were combined by locations and years. A mixed model was chosen to calculate the "F" ratios. Replications, locations, and years were considered to produce random effects, with varieties as fixed variables. Varietal differences were determined by use of Duncan's New Multiple Range Test at the 5% probability level.

RAINFALL DISTRIBUTION

Daily rainfall totals were grouped into 10- or 11-day intervals for July and August in each of the four years for each location. The number of days during an interval when between .01 and .19 inch of rainfall occurred and when .20 inch or more of rainfall was recorded is shown in Figures 1 and 2. This was during the blooming and pod filling stages of development, a time of critical moisture need.

Table 2.—Variety descriptive traits and reaction to major soybean pests in Louisiana

Group & Variety	Parentage	Year released	Flower color	Pubescence color	Hilum color	Resistance				
						Phytophthora[1] root rot	Root-knot[1] nematode	Cyst[1] nematode	Bacterial[1] pustule	Target[1] spot
Group V										
Dare	D52-810 x Hill	1965	W	G	B	MR	MR	S	R	M
Hill	D632-15 x D49-2525	1959	W	Bn	Lt Bn	MR	R	S	R	MR
Group VI										
Curtis	Selection from Lee	1962	P	G	Lt Bn	—	S	S	—	—
Davis	D49-2573 x N45-1497	1965	W	G	B	R	S	S	R	R
Hood	Roanoke x N45-745	1958	P	G	B	MS	S	S	R	R
Lee	S-100 x CNS	1954	P	Bn	Bk	MR	S	S	R	R
Lee 68	Lee (6) x Arksoy	1968	P	Bn	Bk	R	S	S	R	R
Pickett	NC55-1 x [D49-2491 (6) x Dorman]	1965	P	G	Bn Bk	MS	S	R	R	MR
Group VII										
Bossier	Selection from Lee	1962	P	Bn	Dk Bn	MR	S	S	R	R
Bragg	Jackson x D49-2491	1963	W	Bn	Bk	MR	R	S	R	R
Semmes	D51-5427 x D49-2491	1965	P	G	Bn Bk	R	S	S	R	MR
Group VIII										
Hampton 226A	Majos x Lee	1968	P	G	B	VS	S	S	R	R

W = white
P = purple
B = buff
Bk = black

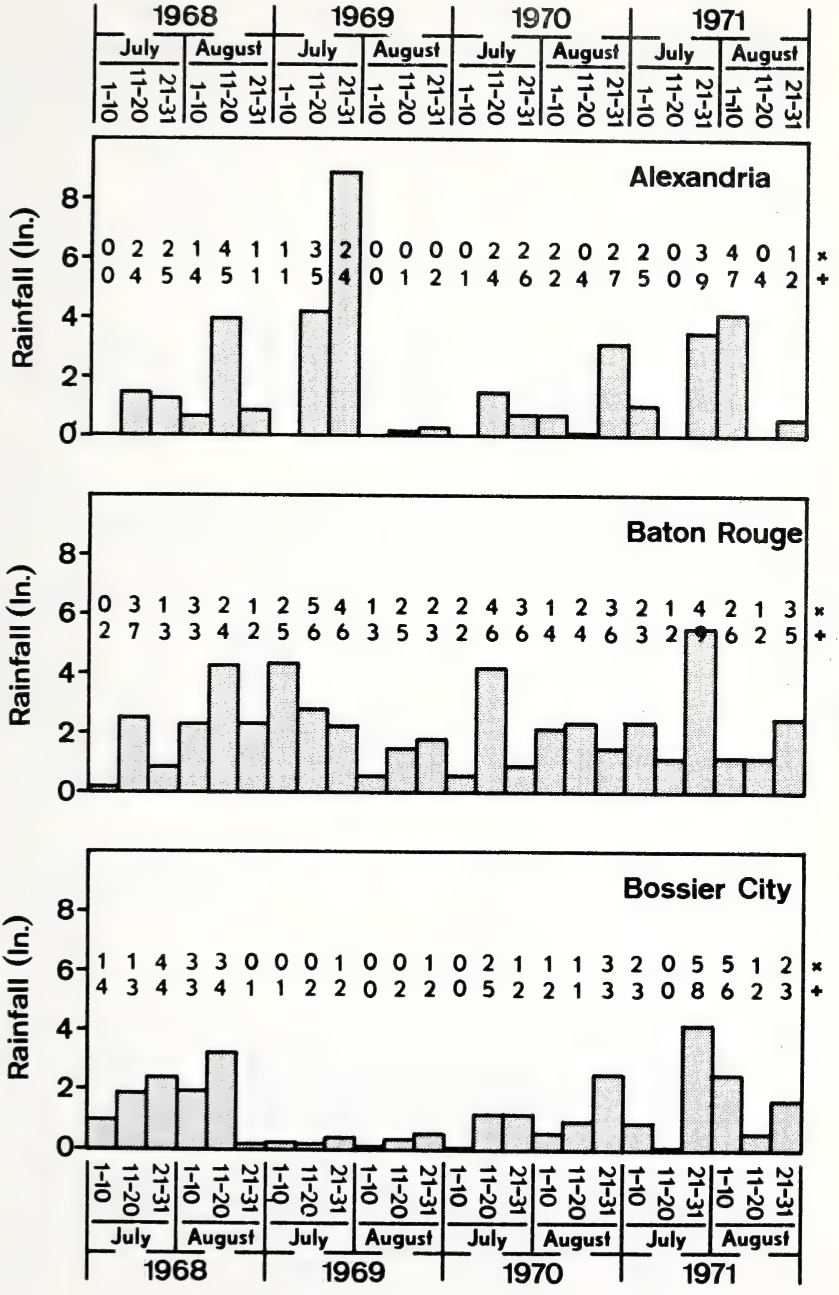
G = gray
Lt Bn = light brown
Bn = brown
Dk Bn = dark brown

Bn Bk = brownish-black
R = resistant
MR = moderately resistant
M = moderate

MS = moderately susceptible
S = susceptible
VS = very susceptible

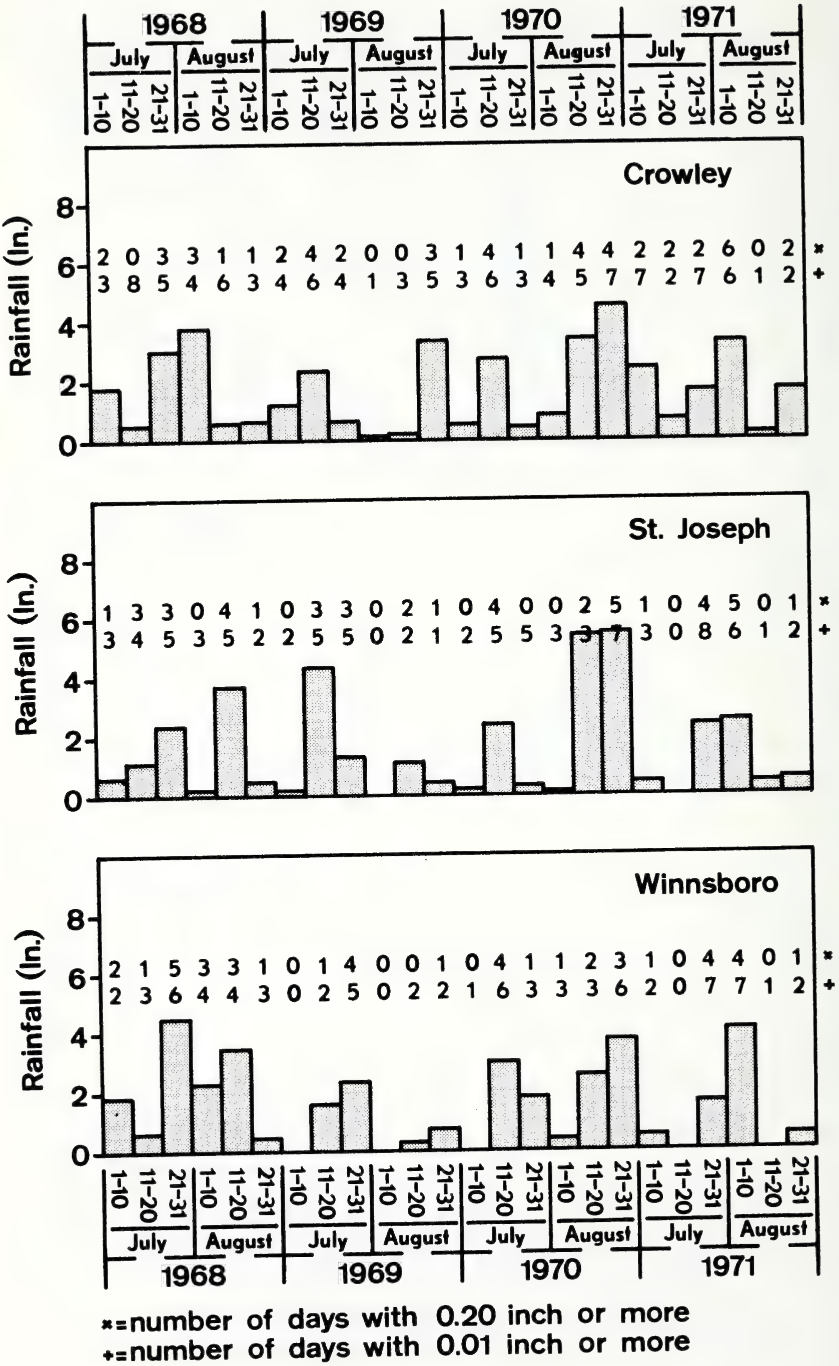
[1] Information obtained from Information Sheet 1060, Mississippi State University Agricultural Experiment Station.

Figure 1. Rainfall distribution during July and August for 1968-1971 at Alexandria, Baton Rouge and Bossier City.



×= number of days with 0.20 inch or more
+= number of days with 0.01 inch or more

Figure 2. Rainfall distribution during July and August for 1968-1971 at Crowley, St. Joseph and Winnsboro.



RESULTS

The combined analysis of variance for yield for all years, locations, and varieties is presented in Table 3. Significant differences occurred for years, locations, varieties, and the several interactions, as was expected since the varieties covered a wide range in maturity. The combined analysis of variance for four selected plant characters is presented in Table 4. There were differences among varieties for plant height, lodging, shattering, and height of lower pods. On the average, plants were taller, lodged more, and shattered more and lower pods were higher at some locations than others. Also, plants grew taller, lodged more, and shattered more in some years. The significant variety x location interaction for plant height and shattering indicated that some varieties were taller and shattered more than others as an average of all locations. The non-significant variety x location interaction for lodging means that a variety that lodged did so at all locations. Height of lower pods was not affected by years.

Table 3.—Combined analysis of variance for yield of 12 soybean varieties grown at six locations in Louisiana, 1968-71

Source	df	MS	F[1]
Total	1103		
Year	3	8996.54	3.76*
Location	5	7294.83	3.05*
Year x Location	15	2393.68	26.38**
Error "a"	68	90.74	
Variety	11	422.38	2.61**
Year x Variety	33	80.44	1.66*
Location x Variety	55	100.02	2.07**
Year x Loc. x Var.	165	48.37	3.91**
Error "b"	748	12.38	

*Significant at the 5% level.

**Significant at the 1% level.

[1] Mixed model where locations, years, and reps are random effects and varieties are fixed variables.

Table 4.—"F" values of combined analysis of variance of plant height, lodging, shattering, and height of lower pods for 12 soybean varieties tested at six locations in Louisiana, 1968-71

	"F" values			
Source	Plant height	Lodging	Shattering	Height of lower pods
Year	14.83**	7.85**	6.13**	1.81
Location	92.73**	15.13**	17.00**	17.90**
Variety	42.53**	4.35**	8.11**	14.19**
Loc. x Var.	1.63**	0.87	3.45**	0.79
C.V. (%)	9.9	38.8	27.7	21.6

**Significant at 1% level of probability.

As shown in Table 5, Davis, Dare, and Bossier soybeans yielded significantly more than the other varieties as an average of locations and years. Mean yields as an average of years and varieties are reported in Table 6. They ranged from 44.7 bushels at Alexandria to 28.3 bushels at Winnsboro. As an average of varieties and locations, mean yields reported in Table 7 were highest in 1968 and lowest in 1969. Rainfall distribution during the growing season was good in 1968, while long dry periods were experienced in 1969, and rainfall was excessive at times in 1970 and 1971.

Consistency of yield of the varieties in each of the four years is shown in Table 8. Yields as an average of years are presented for each of the six locations in Table 9.

Table 5.—Mean yield per acre, plant height, lodging, shattering, and height of lower pods of 12 soybean varieties as an average of locations and years

Variety	Yield bu/ac.[1]	Plant height, inches	Lodging[2]	Shattering[3]	Height of lower pods, inches
Davis	38.3 a	34.7	2.2	1.5	5.6
Dare	37.6 a	29.0	1.7	1.5	4.7
Bossier	37.5 a	36.6	2.7	1.1	6.7
Bragg	36.4 b	40.1	2.4	1.1	7.1
Lee	36.3 b	28.7	1.7	1.1	4.8
Hood	36.2 b	29.4	2.0	1.5	4.8
Pickett	35.9 bc	29.1	1.8	1.1	5.3
Curtis	35.5 bc	32.1	2.3	1.1	5.4
Hampton 266A	35.0 c	39.0	2.7	1.1	6.8
Lee 68	34.1 d	29.8	1.9	1.2	4.6
Semmes	33.2 d	35.6	1.8	1.1	6.6
Hill	30.5 e	27.2	2.2	1.5	4.4

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] 1 = almost all plants errect, 5 = all plants down badly.

[3] 1 = no shattering, 5 = over 20% shattered.

Table 6.—Mean yield per acre, plant height, lodging, shattering, and height of lower pods of 12 soybean varieties as an average of years and varieties

Location	Yield, bu/ac.	Plant height, inches	Lodging[1]	Shattering[2]	Height of lower pods, inches
Alexandria	44.7	36.5	1.8	1.2	5.9
St. Joseph	39.4	37.2	2.8	1.0	6.6
Baton Rouge	38.8	31.9	2.3	1.4	4.8
Crowley	32.2	24.8	1.6	1.1	4.4
Bossier City	30.5	33.5	2.5	1.2	5.6
Winnsboro	28.3	31.4	1.5	1.7	6.2

[1] 1 = almost all plants erect, 5 = all plants down badly.

[2] 1 = no shattering, 5 = over 20% shattered.

Table 7.—Mean yield per acre, plant height, lodging, shattering, and height of lower pods of 12 soybean varieties as an average of varieties and locations

Year	Yield, bu/ac.	Plant height, inches	Lodging[1]	Shattering[2]	Height of lower pods, inches
1968	43.4	34.5	2.3	1.3	5.4
1970	35.0	33.0	2.7	1.0	5.9
1971	33.9	31.8	1.9	1.2	5.7
1969	29.6	31.1	1.8	1.3	5.2

[1] 1 = almost all plants erect, 5 = all plants down badly.
[2] 1 = no shattering, 5 = over 20% shattered.

Table 8.—Mean yield and rank of 12 soybean varieties by years as an average of locations

Variety	Year and Rank							
	1968	Rank	1969	Rank	1970	Rank	1971	Rank
	Bushels per acre							
Davis	46.8	1	31.6	2	37.2	2	37.4	2
Dare	46.4	3	27.4	10-11	37.3	3	38.7	1
Bossier	45.4	4	32.1	1	36.6	4	35.7	4
Bragg	43.8	6	30.8	6	37.9	1	33.1	8
Lee	44.0	5	30.7	7	35.4	7	34.8	5
Hood	43.5	7	28.7	9	34.7	8-9	37.3	3
Pickett	43.1	8	30.9	5	35.8	6	33.5	6
Curtis	42.2	9	29.6	8	36.5	5	33.4	7
Hampton 266A	46.5	2	31.1	4	32.9	10	29.6	12
Lee 68	41.6	10	31.5	3	31.3	11	32.0	9
Semmes	39.0	11	27.4	10-11	34.7	8-9	31.5	10
Hill	38.2	12	23.7	12	29.5	12	30.3	11

Table 9.—Mean yield per acre of 12 soybean varieties by location as an average of years

Variety	Location					
	Baton Rouge	Bossier City	Crowley	Winnsboro	St. Joseph	Alexandria
	Bushels per acre					
Davis	41.3 ab[1]	32.2 bc	35.9 a	29.1 bcd	43.1 ab	49.1 a
Dare	40.4 abc	32.2 bc	32.1 c	29.4 bc	44.8 a	47.4 abc
Bossier	39.2 bcd	36.0 a.	35.3 ab	31.3 ab	35.3 h	48.4 ab
Bragg	39.1 bcd	27.0 d	31.0 c	32.6 a	41.9 bcd	47.3 abcd
Lee	41.0 abc	33.9 ab	31.9 c	25.8 e	40.2 cde	46.0 bcd
Hood	39.5 bc	29.6 c	33.5 abc	27.9 cde	42.2 abc	45.2 cde
Pickett	42.6 a	30.9 c	33.4 abc	27.5 cde	36.7 fgh	44.5 def
Curtis	40.5 abc	31.6 bc	32.8 bc	27.9 cde	37.8 efgh	42.8 ef
Hampton 266A	38.3 cd	32.0 bc	33.2 abc	29.3 bcd	38.5 efg	39.3 g
Lee 68	38.1 cd	30.8 c	32.0 c	22.5 f	36.6 fgh	45.5 cde
Semmes	36.5 d	26.3 de	32.3 c	26.9 de	36.0 gh	41.9 f
Hill	28.9 e	23.8 e	23.6 d	28.9 bcd	39.3 def	39.1 g

[1] Mean yields per acre followed by a letter in common are not satistically different at the 5% level of probability.

Since no one can accurately predict the weather and because a farmer is normally restricted to one area, state average yields are of limited value to him. For this reason, the mean performance of the 12 varieties is shown for the individual locations in Tables 10-15. The varieties are grouped by maturity and yield. Dare yielded significantly more than Hill at all locations except Winnsboro. Davis had the highest four-year average yield of the Group VI varieties at Alexandria, Crowley, St. Joseph, and Winnsboro. Pickett had the largest yield of this group at Baton Rouge, while Lee yielded more at Bossier City. Of the Group VII varieties, Bossier had the highest average yield at Alexandria, Baton Rouge, Bossier City, and Crowley, but Bragg was first at St. Joseph and Winnsboro.

Other varieties, in addition to the 12 referred to above, were included in the tests for one or more years. Mean yields for all the varieties tested in a given year are presented by locations in Tables 16-21.

Table 10.—Mean performance of 12 soybean varieties at Alexandria, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	47.4 abc	Sept. 26	35	1.8	1.4	5.6
Hill	39.1 g	Sept. 20	32	1.8	1.3	5.0
Group VI						
Davis	49.1 a	Oct. 23	38	2.0	1.1	5.5
Lee	46.0 bcd	Oct. 14	34	1.4	1.0	5.5
Lee 68	45.5 cde	Oct. 15	36	1.6	1.4	4.5
Hood	45.2 cde	Oct. 1	34	1.5	1.2	5.2
Pickett	44.7 def	Oct. 15	32	2.0	1.1	5.9
Curtis	42.8 ef	Oct. 6	34	2.5	1.1	5.5
Group VII						
Bossier	48.4 ab	Oct. 27	38	1.5	1.1	6.5
Bragg	47.3 abcd	Oct. 26	46	1.1	1.0	7.1
Semmes	41.9 f	Oct. 18	38	1.6	1.0	7.9
Group VIII						
Hampton 266A	39.3 g	Oct. 31	38	2.5	1.4	6.5

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 21.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered.

Table 11.—Mean performance of 12 soybean varieties at Baton Rouge, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	40.4 abc	Sept. 29	28	1.5	1.5	3.6
Hill	28.9 e	Sept. 9	28	2.7	1.4	3.8
Group VI						
Pickett	42.6 a	Oct. 19	28	2.4	1.1	4.7
Davis	41.3 ab	Oct. 12	34	2.0	1.7	4.6
Lee	41.0 abc	Oct. 22	29	2.0	1.3	4.4
Curtis	40.5 abc	Oct. 18	32	2.4	1.4	4.9
Hood	39.5 bc	Oct. 4	27	1.8	1.7	4.1
Lee 68	38.1 cd	Oct. 22	29	2.4	1.3	4.2
Group VII						
Bossier	39.2 bcd	Oct. 29	36	3.2	1.2	5.8
Bragg	39.1 bcd	Oct. 26	38	2.7	1.4	6.2
Semmes	36.5 d	Oct. 24	35	1.6	1.3	5.7
Group VIII						
Hampton 266A	38.3 cd	Nov. 4	38	2.9	1.2	5.5

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 16.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered.

Table 12.—Mean performance of 12 soybean varieties at Bossier City, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	32.2 bc	Sept. 30	27	2.3	1.1	4.8
Hill	23.8 e	Sept. 20	24	2.3	2.2	4.0
Group VI						
Lee	33.9 ab	Oct. 20	31	2.2	1.0	4.6
Davis	32.2 bc	Oct. 20	33	2.6	1.1	5.2
Curtis	31.6 bc	Oct. 16	33	2.4	1.0	6.4
Pickett	30.9 c	Oct. 17	33	2.1	1.0	5.7
Lee 68	30.8 c	Oct. 20	32	2.2	1.0	4.5
Hood	29.6 c	Oct. 7	30	2.3	1.6	4.1
Group VII						
Bossier	36.0 a	Oct. 28	40	2.8	1.0	7.3
Bragg	27.0 d	Oct. 25	42	3.2	1.0	7.4
Semmes	26.3 de	Oct. 22	35	2.0	1.0	6.2
Group VIII						
Hampton 266A	32.0 bc	Nov. 4	42	3.5	1.0	7.0

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 21.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered.

Table 13.—Mean performance of 12 soybean varieties at Crowley, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	32.1 c	Oct. 4	20	1.2	1.0	3.2
Hill	23.6 d	Sept. 30	20	1.6	1.0	2.8
Group VI						
Davis	35.9 a	Oct. 17	28	1.6	1.2	4.8
Hood	33.5 abc	Oct. 4	22	1.2	1.5	4.0
Pickett	33.4 abc	Oct. 14	20	1.0	1.0	3.6
Curtis	32.8 bc	Oct. 20	26	2.2	1.0	5.6
Lee 68	32.0 c	Oct. 22	20	1.3	1.0	3.0
Lee	31.9 c	Oct. 24	20	1.2	1.0	3.3
Group VII						
Bossier	35.3 ab	Oct. 31*	29	2.8	1.0	5.1
Semmes	32.3 c	Oct. 24	29	1.3	1.0	5.9
Bragg	31.0 c	Oct. 22*	32	2.5	1.0	6.1
Group VIII						
Hampton 266A	33.2 abc	Nov. 1*	32	1.7	1.0	5.3

*Maturity date in 1968 only; others average of 1968 and 1971.

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 13.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered.

Table 14.—Mean performance of 12 soybean varieties at St. Joseph, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	44.8 a	Sept. 23	36	2.2	1.0	5.7
Hill	39.3 def	Sept. 12	33	2.9	1.0	5.7
Group VI						
Davis	43.1 ab	Oct. 13	41	3.6	1.0	6.9
Hood	42.2 abc	Oct. 2	33	3.0	1.0	5.5
Lee	40.2 cde	Oct. 19	33	2.1	1.0	6.6
Curtis	37.8 efgh	Oct. 17	34	2.8	1.0	5.1
Pickett	36.7 fgh	Oct. 15	32	1.6	1.0	5.8
Lee 68	36.6 fgh	Oct. 19	32	2.3	1.0	6.4
Group VII						
Bragg	41.9 bcd	Oct. 26	43	3.2	1.0	8.2
Semmes	36.0 gh	Oct. 18	42	2.7	1.0	7.3
Bossier	35.3 h	Oct. 28	41	3.8	1.0	7.8
Group VIII						
Hampton 266A	38.5 efg	Nov. 2	48	4.0	1.0	8.8

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 15.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered (data taken at maturity).

Table 15.—Mean performance of 12 soybean varieties at Winnsboro, 1968-1971

Group & Variety	Yield bu/ac.[1]	Maturity date[2]	Plant height, inches	Lodging[3]	Shattering[4]	Height of lower pods, inches
Group V						
Dare	29.4 bc	Sept. 30	28	1.2	3.4	5.4
Hill	28.9 bcd	Sept. 25	26	2.0	2.3	4.9
Group VI						
Davis	29.1 bcd	Oct. 14	34	1.3	2.9	6.9
Curtis	27.9 cde	Oct. 18	34	1.5	1.0	4.9
Hood	27.9 cde	Oct. 4	31	1.7	2.3	6.1
Pickett	27.5 cde	Oct. 18	29	1.3	1.3	5.9
Lee	25.8 e	Oct. 22	24	1.2	1.0	4.2
Lee 68	22.5 f	Oct. 23	29	1.5	1.2	5.2
Group VII						
Bragg	32.6 a	Oct. 30	39	1.6	1.0	7.9
Bossier	31.3 ab	Oct. 31	34	1.9	1.0	7.7
Semmes	26.9 de	Oct. 18	34	1.4	1.6	6.7
Group VIII						
Hampton 266A	29.3 bcd	Oct. 30	34	1.3	1.0	8.0

[1] Mean yields per acre followed by a letter in common are not significantly different at the 5% level of probability.

[2] Average planting date was May 22.

[3] 1 = almost all plants erect, 5 = all plants down badly.

[4] 1 = no shattering, 5 = over 20% shattered.

Table 16.—Mean yield per acre of commercial soybean varieties tested at Alexandria in the years 1968-1971

	Yield per acre in bushels[1]			
Variety	1968	1969	1970	1971
Davis	52.6 a	58.8 a	45.7 ab	40.2 abc
Dare	46.6 bcd	53.7 bcd	49.2 a	40.0 abcd
Bossier	46.4 bcd	56.0 ab	47.2 ab	43.4 ab
Bragg	45.1 bcd	51.4 cde	48.0 a	44.2 a
Lee	48.5 ab	55.6 abc	42.1 bc	38.3 cd
Hood	46.6 bcd	54.2 bcd	44.4 abc	35.8 cd
Pickett	42.8 cd	51.3 cde	45.7 ab	38.5 cd
Curtis	42.5 cd	46.1 g	44.0 abc	38.5 cd
Hampton 266A	46.1 bcd	50.2 def	33.8 e	28.7 e
Lee 68	47.0 bc	55.6 abc	44.5 abc	35.2 d
Semmes	41.1 d	46.0 g	44.4 abc	35.7 cd
Hill	41.3 d	46.5 fg	39.0 cd	30.0 e
Hardee	29.5 f	—	—	—
York	34.6 e	52.8 bcde	—	—
Bienville	34.7 e	—	—	—
Coker 318	—	39.3 h	33.1 e	—
Coker 208	—	49.2 efg	35.8 de	29.0 e
Ransom	—	—	47.6 ab	39.3 bcd
Pickett 71	—	—	42.2 bc	36.9 cd
McNair 800	—	—	—	38.5 cd
C.V. (%)	6.8	5.2	7.9	7.7

[1] Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 17.—Mean yield per acre of commercial soybean varieties tested at Baton Rouge in the years 1968-1971

	Yield per acre in bushels[1]			
Variety	1968	1969	1970	1971
Davis	50.6 a	25.1 bcd	42.8 abc	42.7 a
Dare	47.3 ab	20.1 de	46.5 a	42.5 a
Bossier	50.6 a	26.2 bcd	38.0 bcd	38.7 abc
Bragg	41.3 cd	27.4 bc	44.8 ab	40.1 ab
Lee	49.3 a	29.1 b	42.2 abc	40.6 ab
Hood	44.8 bc	21.3 cde	46.6 a	41.1 a
Pickett	47.9 ab	40.4 a	41.7 abcd	39.9 ab
Curtis	51.2 a	27.2 bc	42.3 abc	37.8 abcd
Hampton 266A	48.8 a	27.7 bc	40.1 abcd	34.0 cd
Lee 68	48.0 ab	26.6 bc	34.9 de	40.2 ab
Semmes	41.1 cd	29.6 b	38.1 bcd	35.5 bcd
Hill	36.3 e	16.1 e	31.4 e	28.7 e
Hardee	41.1 cd	—	—	—
York	40.5 d	12.7 f	—	—
Bienville	31.6 f	—	—	—
Coker 318	—	26.9 bc	38.6 bcd	—
Coker 208	—	25.8 bcd	41.1 abcd	32.6 e
Ransom	—	—	44.0 ab	33.2 de
Pickett 71	—	—	36.1 cde	33.3 de
McNair 800	—	—	—	40.1 ab
C.V. (%)	5.4	13.1	10.2	8.6

[1] Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 18.—Mean yield per acre of commercial soybean varieties tested at Bossier City in the years 1968-1971

Variety	Yield per acre in bushels[1]			
	1968	1969	1970	1971
Davis	45.2 bc	18.3 abc	26.5 abcd	35.1 abcd
Dare	44.6 bcd	8.4 d	27.2 abcd	42.7 a
Bossier	50.6 a	18.7 abc	31.2 a	38.9 ab
Bragg	45.7 bc	17.9 abc	22.9 cd	19.0 e
Lee	46.0 bc	18.7 abc	31.0 a	35.9 abc
Hood	39.7 ef	14.9 bcd	21.1 d	38.9 ab
Pickett	44.9 bc	12.4 cd	27.9 abcd	33.8 abcd
Curtis	44.4 bcde	16.9 abc	30.2 ab	31.3 bcd
Hampton 266A	49.3 ab	22.7 a	22.0 cd	31.6 abcd
Lee 68	41.4 cdef	21.2 ab	28.4 abc	29.6 bcde
Semmes	41.1 cdef	12.7 cd	23.5 bcd	24.5 cde
Hill	27.2 g	8.1 d	21.2 d	34.8 abcd
Hardee	41.4 cdef	—	—	—
York	37.0 f	9.3 d	—	—
Bienville	40.3 def	—	—	—
Coker 318	—	19.5 abc	11.6 e	—
Coker 208	—	18.1 abc	21.0 d	24.0 de
Ransom	—	—	24.8 abcd	30.8 bcd
Pickett 71	—	—	25.4 abcd	29.4 bcde
McNair 800	—	—	—	26.1 cde
C.V. (%)	6.9	25.0	17.1	21.5

[1]Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 19.—Mean yield per acre of commercial soybean varieties tested at Crowley in the years 1968-1971

Variety	Yield per acre in bushels[1]			
	1968	1969	1970	1971
Davis	44.3 ab	26.8 cd	40.0 a	32.4 ab
Dare	45.3 a	18.2 e	32.1 cd	32.9 ab
Bossier	45.0 ab	34.2 a	36.1 abc	26.0 cde
Bragg	40.0 cd	28.7 bcd	34.1 bc	21.4 fg
Lee	44.7 ab	26.3 d	28.4 de	27.9 cd
Hood	43.2 ab	21.8 e	33.5 bc	35.4 a
Pickett	43.5 ab	25.7 d	36.4 ab	27.9 cd
Curtis	39.4 de	29.0 bcd	37.6 ab	25.1 cdef
Hampton 266A	45.7 a	31.2 abc	35.8 abc	20.3 g
Lee 68	42.3 bc	31.6 ab	26.5 e	27.5 cd
Semmes	39.3 de	27.4 bcd	37.6 ab	24.6 def
Hill	36.8 ef	10.6 f	24.9 e	21.9 efg
Hardee	38.5 de	—	—	—
York	35.0 f	9.6 f	—	—
Bienville	37.7 def	—	—	—
Coker 318	—	29.6 bcd	27.8 de	—
Coker 208	—	27.1 cd	32.0 cd	20.9 fg
Ransom	—	—	37.0 ab	29.4 bc
Pickett 71	—	—	37.1 ab	27.0 cd
McNair 800	—	—	—	26.6 cd
C.V. (%)	4.4	10.8	8.8	9.9

[1]Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 20.—Mean yield per acre of commercial soybean varieties tested at St. Joseph in the years 1968-1971

Variety	Yield per acre in bushels[1]			
	1968	1969	1970	1971
Davis	49.4 ab	44.4 a	30.7 bcde	45.0 ab
Dare	51.8 a	42.2 abc	36.4 a	46.5 a
Bossier	39.8 f	37.8 efg	25.5 f	36.5 def
Bragg	47.7 abc	41.4 abcd	34.6 abc	42.2 bc
Lee	44.8 cde	40.9 bcd	31.9 bcd	41.2 bc
Hood	47.2 bcd	41.4 abcd	35.1 ab	43.2 abc
Pickett	43.2 def	41.5 abcd	25.0 f	34.3 efg
Curtis	40.7 ef	40.7 cde	27.9 def	39.4 cd
Hampton 266A	49.4 ab	42.5 ab	27.3 def	32.0 g
Lee 68	39.8 f	41.0 bcd	26.1 ef	36.9 de
Semmes	41.1 ef	35.2 gh	25.5 f	39.4 cd
Hill	40.8 ef	41.9 abcd	30.3 cde	42.4 bc
Hardee	21.6 g	—	—	—
York	39.6 f	37.0 fgh	—	—
Bienville	39.8 f	—	—	—
Coker 318	—	34.1 h	20.5 g	—
Coker 208	—	38.7 def	24.9 f	33.0 fg
Ransom	—	—	30.9 bcde	33.2 efg
Pickett 71	—	—	25.4 f	36.8 de
McNair 800	—	—	—	40.7 c
C.V. (%)	6.6	4.9	8.7	6.3

[1] Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 21.—Mean yield per acre of commercial soybean varieties tested at Winnsboro in the years 1968-1971

Variety	Yield per acre in bushels[1]			
	1968	1969	1970	1971
Davis	40.3 bc	11.0 bcd	30.0 abc	24.8 abcd
Dare	42.7 ab	15.4 ab	17.2 ef	20.5 cd
Bossier	40.8 bc	15.1 ab	35.0 a	28.1 abcd
Bragg	43.1 ab	13.7 abc	29.8 abc	30.2 ab
Lee	31.7 d	10.4 cde	16.5 f	20.7 bcd
Hood	40.3 bc	13.8 abc	22.2 bcdef	26.7 abcd
Pickett	36.1 cd	11.9 bcd	21.9 cdef	20.5 cd
Curtis	35.1 cd	13.8 abc	26.2 abcde	23.2 abcd
Hampton 266A	39.8 bc	9.3 de	29.6 abc	28.7 abc
Lee 68	32.5 d	9.0 de	21.3 cdef	18.1 d
Semmes	30.6 d	10.4 cde	26.4 abcde	25.8 abcd
Hill	47.3 a	13.4 abcd	19.9 def	21.8 bcd
Hardee	30.4 d	—	—	—
York	31.5 d	17.3 a	—	—
Bienville	34.6 cd	—	—	—
Coker 318	—	6.6 e	30.1 abc	—
Coker 208	—	9.3 de	28.6 abcd	18.3 d
Ransom	—	—	31.8 ab	32.2 a
Pickett 71	—	—	16.2 f	24.9 abcd
McNair 800	—	—	—	25.1 abcd
C.V. (%)	11.0	22.3	23.4	21.0

[1] Mean yields per acre followed by a letter in common are not statistically different at the 5% level of probability.

Table 22.—Soybean varieties in the 1968-1971 commercial variety trials in Louisiana, showing the release date and where developed

Variety	Year released	Primary developing organization
Bienville	1958	Louisiana Agricultural Experiment Station*
Bossier	1962	Red River Valley Agricultural Experiment Station, Louisiana
Bragg	1963	Florida Agricultural Experiment Station*
Coker 208	1970	Coker's Pedigreed Seed Company, South Carolina
Coker 318	—	Coker's Pedigreed Seed Company, South Carolina
Curtis	1962	Red River Valley Agricultural Experiment Station, Louisiana
Dare	1965	North Carolina Agricultural Experiment Station*
Davis	1965	Arkansas Agricultural Experiment Station*
Hampton 266A	1968	Coker's Pedigreed Seed Company, South Carolina
Hardee	1962	Florida Agricultural Experiment Station*
Hill	1959	Delta Branch Agricultural Experiment Station, Mississippi*
Hood	1958	Delta Branch Agricultural Experiment Station, Mississippi*
Lee	1954	Delta Branch Agricultural Experiment Station, Mississippi*
Lee 68	1968	Arkansas Agricultural Experiment Station*
McNair 800	1969	McNair Seed Company, North Carolina
Pickett	1965	North Carolina Agricultural Experiment Station*
Pickett 71	1971	Delta Branch Agricultural Experiment Station, Mississippi*
Ransom	1970	North Carolina Agricultural Experiment Station*
Semmes	1965	Delta Branch Agricultural Experiment Station, Mississippi*
York	1967	Virginia Agricultural Experiment Station*

*Cooperative program with the U.S. Regional Soybean Laboratory.

RECOMMENDATIONS

The primary purpose of variety trials is to provide data on the relative performance of the soybean varieties being grown in Louisiana. The data should aid farmers in making a choice of the varieties to plant.

Factors a farmer should consider in choosing a variety are yielding ability within a maturity group, resistance to disease and nematodes, resistance to lodging and shattering, and maturity date. No one variety has all the desirable traits for all situations. Tests reported herein were conducted on soils where diseases and nematodes were not known to be a problem.

Each of the 12 varieties tested in all four years is recommended throughout Louisiana, with the exception of the Hill variety. This variety should not be planted in southern Louisiana because maturity occurs during hot, rainy weather, which may cause poor seed quality.

Davis, Lee 68, and Semmes are resistant to *Phytophthora* root rot and are highly recommended for planting on heavy, poorly drained soils. Picket is resistant to race 3 of the soybean cyst nematode and to the reniform nematode. Pickett will normally give higher yields than a susceptible variety on cyst or reniform infested soil.

Bragg and Hill are resistant to some races of root-knot nematode and should be planted if this pest is a problem. Hampton 266A is highly susceptible to *Phytophthora* root rot and should not be planted on soils infested with this organism. Semmes, Bragg, Bossier, and Hampton 266A set their bottom pods 6 to 8 inches above the soil and are recommended for planting in new-ground.

three years was $69.94 per acre for rotation grazing and $52.32 for continuous grazing.

5. These grazing trials indicate that the grazing of Coastal bermudagrass with stocker cattle can be profitable and should be considered by Louisiana landowners as an efficient land use alternative.

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Coastal Bermudagrass Pastures for Grazing Calves and Yearlings In Louisiana

W. M. Oliver

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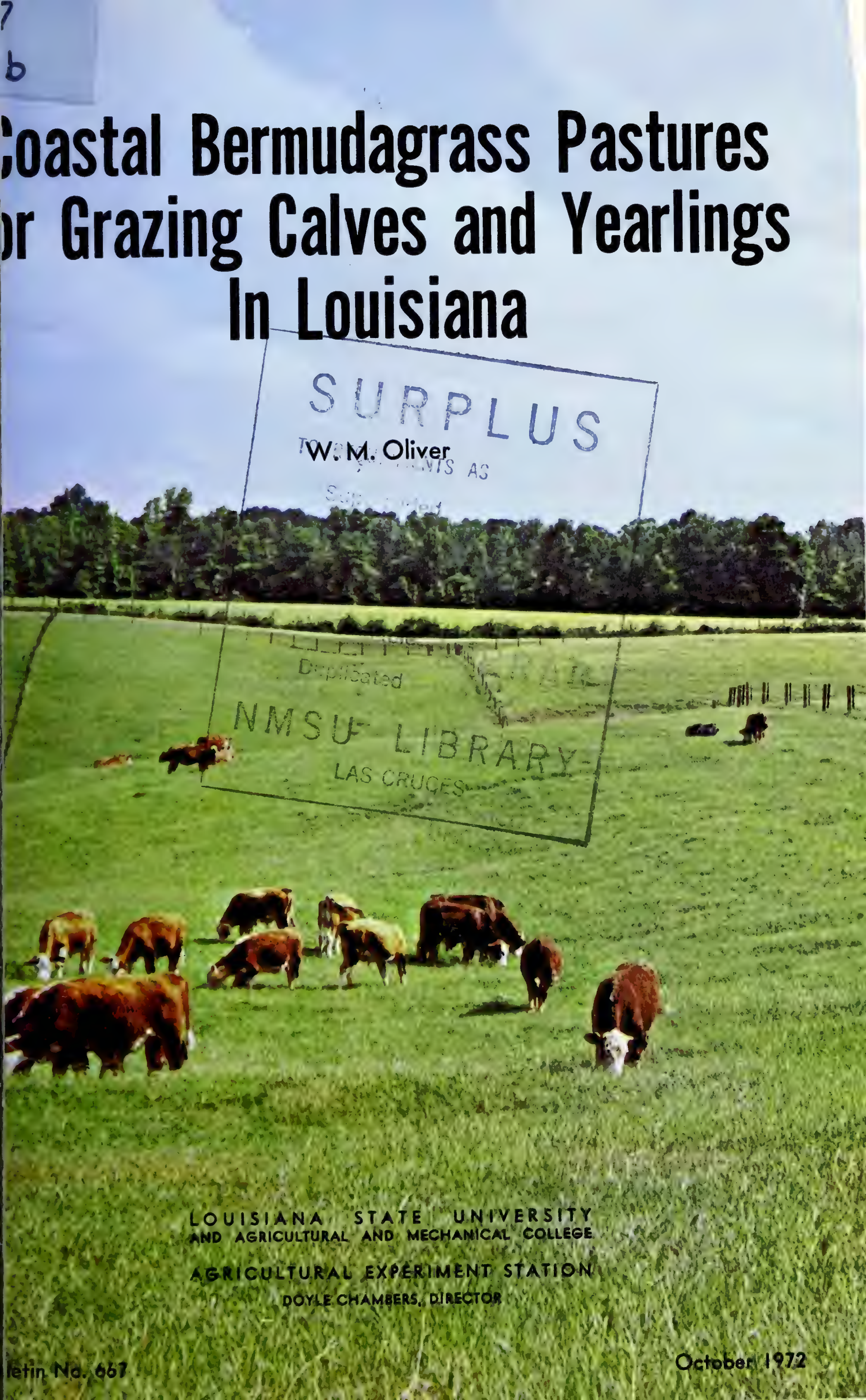

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PREFACE

Thousands of stocker calves and yearlings are produced annually in Louisiana. Many of these cattle are sold and shipped out of the state soon after weaning. Coastal bermudagrass is well adapted in Louisiana, especially in the Coastal Plain Region of the northern portion of the state. The studies reported here show that both calves and yearling cattle can be profitably carried through the growing phase of beef production on Coastal bermudagrass pastures in Louisiana.

Widespread adoption of the practice of grazing stocker cattle on well-managed Coastal bermudagrass pastures through the spring and summer months could mean millions of dollars in increased income to cattle producers in Louisiana.

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Coastal Bermudagrass Pastures For Grazing Calves and Yearlings In Louisiana

W. M. OLIVER[1]

INTRODUCTION

Cattle that are finally slaughtered as fed beef are carried through three production phases between birth and slaughter at 18 to 30 months of age. Until the calves are 6 to 9 months old, they are kept with their mothers and depend on both milk and forage for the nutrients required for preweaning growth. After weaning, the cattle are carried through a growing or stocker phase during which the increase in body size is composed primarily of skeletal and muscular growth. This production phase occurs during all or a part of the animal's life between 6 and 24 months of age. During this growing phase, the animals depend almost entirely on forage for the nutrients needed for growth because the primary purpose of this production phase is to increase body weight at a low cost. Following the stocker phase, the cattle are carried through a finishing or fattening period during which the primary objective is to improve the quality grade of the animal's carcass by increasing the fat content of its body. Fattening is, of course, accompanied by some increase in bone and muscle weight. To achieve the fattening necessary for improving the quality grade, the animal must be fed a ration containing a high proportion of grain for a period of 3 to 6 months. Today, about 80 percent of the cattle slaughtered in the United States are fed cattle weighing 950 to 1,150 pounds with a quality grade of High Good to Choice.

The growing or stocker phase of slaughter beef production is carried on in many different ways. Many cattle are grown with warm-season perennial grasses found on native range land of the Midwest and Southwest. The Osage Country of Oklahoma, the Flint Hills of Kansas, and the Sand Hills of Nebraska are well known as areas where stocker cattle are grazed. Other cattle are grazed on winter wheat fields in Western Texas, Oklahoma, and Kansas. Some are grown under feedlot conditions in the cattle finishing areas with high roughage rations such as silage. The objective is a reasonable increase in body size on relatively cheap feed.

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A high percentage of the calves produced in beef cow herds of the Southeastern United States are sold at weaning time to stocker operators who carry them through the growing phase in other sections of the country. At the same time, the Southeastern United States has an advantage over other portions of the nation in its potential for forage production due to a longer growing season, more adequate rainfall, and soils which respond to fertilization. These natural advantages give this region the opportunity to carry calves through the stocker phase of production in an intensive and profitable manner. In recent years, a considerable number of stocker calves have been successfully grown in the Southeast by utilizing cool-season annual plants grown on cultivated land for forage. One of the objectives of this study was to evaluate the potential for growing stocker cattle in this region by using a warm-season perennial plant—Coastal bermudagrass—for forage.

Coastal bermudagrass is a warm-season perennial forage plant that was developed through extensive crossbreeding and selection by Dr. G. W. Burton of the Georgia Coastal Plain Experiment Station more than 20 years ago. It is widely adapted and is now grown throughout the entire Coastal Plain Region of the United States. Although it produces no viable seed, a cover of Coastal bermudagrass can be established rather easily in one growing season. Coastal bermudagrass may be grown on a wide range of soils and it will produce a large volume of forage when grown on the poorer upland soils of the Coastal Plain because it responds efficiently to high levels of fertilization. Coastal bermudagrass can be grown on soils on steep slopes because the plants produce a thick mat of stems and roots which prevent erosion. Thus, thousands of acres of land in the Southeastern United States that would otherwise be limited to use by woody vegetation may now be used for forage production. Because it produces a very deep root system, Coastal bermudagrass will continue to make rather satisfactory growth during periods of subnormal rainfall when growth by other warm-season forage plants ceases. It seems virtually impossible to kill Coastal bermudagrass by overgrazing if satisfactory fertility levels are maintained.

The forage producing potential of Coastal bermudagrass has been thoroughly tested by experiment stations throughout the South. When compared with other adapted perennials in hay production studies, Coastal bermudagrass has consistently produced 25 to 50 percent more forage per acre. With proper management and fertilization, up to 8 tons of hay per acre have been harvested without irrigation.

The nutritive value of properly managed and harvested Coastal bermudagrass hay has been found to be excellent, with a digestible protein content of 14 to 18 percent and digestible dry matter content above 60 percent. The potential of Coastal bermudagrass in terms of the production of feed nutrients per acre compares very favorably with most grain and forage crops. In one study, two cuttings of properly harvested Coastal bermudagrass hay yielded the same amount of digestible dry matter and twice as many pounds of digestible protein per acre as are contained in 100 bushels of corn. Coastal bermudagrass is widely adapted in the Southeast. It produces a large volume of forage. When properly managed, the forage is high in nutritional value. It appeared logical that the potential of Coastal bermudagrass to provide forage for growing stocker cattle should be evaluated.

The response of stocker cattle grazed on Coastal bermudagrass has been studied in only a limited manner. It has generally been found that beef gain per acre and the number of animal days of grazing obtained from Coastal bermudagrass pastures have been greater than were obtained from other warm-season perennial plants. These findings were largely the result of a greater volume of forage being produced and more animals being grazed. But researchers and producers alike have generally reported that beef gains per animal have been less than desirable, particularly during the latter portion of the grazing season and when younger cattle were grazed. In view of the excellent nutritive content of properly managed and harvested Coastal bermudagrass that has been observed, there seemed to be a possibility that the less than desirable animal performance might have resulted from less than desirable management of the forage rather than the grass itself. It has been observed in hay evaluation that forage harvested when the plant growth was young contained a higher proportion of digestible protein and digestible dry matter than forage harvested when the growth was older. Therefore, it was hypothesized that applying management practices to the grazing of Coastal bermudagrass that would help keep the vegetative plant parts young and immature should result in the production of satisfactory beef gains per animal and per acre. Thus, another objective of this study was to compare the beef gain and returns obtained from a rotational grazing system with that produced by the conventional continuous grazing system.

MATERIALS AND METHODS

Two Coastal bermudagrass pastures, each 10 acres in size, were used in grazing trials during the spring and summer of 1969, 1970, and 1971 to compare weight gains of stocker calves and yearlings grazed continuously and on a rotational system. One pasture was fenced so that the forage in the entire pasture was available for grazing on a continuous basis. The other pasture was crossfenced into four paddocks, each 2.5 acres in size, so that grazing by the cattle could be more systematically regulated by rotating the animals from paddock to paddock. Under the rotation system used, all the cattle were grazed on one paddock at a given time. The animals were systematically moved to a fresh 2.5-acre paddock each Monday morning, Wednesday afternoon, and Friday afternoon. In following this system of rotation, each paddock was grazed approximately 3 days and allowed a period of 10 days for regrowth. Hay was harvested from both pastures when observation indicated that surplus forage was present and needed to be removed to keep the grass in a young, nutritious condition.

In the 1969 and 1971 trials, yearling Hereford steers were grazed. The steers had been weaned the previous fall and wintered to make essentially no weight gain. Spring weaned Hereford steer and heifer calves were grazed in the 1970 trial.

The stocking rates used for the two grazing systems were equal within each trial. The stocking rates used in each of the three trials are shown in Table 1. Under these stocking rates, the grazing pressure on a paddock being grazed under the rotational system was 4.8 yearlings or 2,136 pounds initial liveweight per acre in 1969, 11.2 calves or 3,580 pounds initial liveweight per acre in 1970, and 5.6 yearlings or 2,672 pounds initial liveweight per acre in 1971.

Phosphate and potash were applied to both pastures in March each year based on needs as indicated by soil tests. Each year 300 pounds of 0-20-20 fertilizer per acre was used. In 1969, each pasture was topdressed with 200 pounds of ammonium nitrate per acre on April 1 and near the first of each succeeding month through

TABLE 1.—Stocking Rates for the Continuous and Rotation Grazing Systems During 1969, 1970, and 1971

Year	Kind of cattle	Head per acre	Initial liveweight per acre, lb. Continuous	Rotation
1969	Yearling steers	1.2	530	534
1970	Steer and heifer calves	2.8	873	895
1971	Yearling steers	1.4	618	668

August 1—a total of 1,000 pounds of ammonium nitrate per acre. In 1970, grazing was not initiated until May 13 following weaning of the calves. The first application of ammonium nitrate was therefore delayed until May 1, when 200 pounds per acre was applied. An additional 200 pounds of ammonium nitrate per acre was applied near July 15. In 1971, the pastures were topdressed with 200 pounds of ammonium nitrate per acre on April 1 and on July 1.

In the 1969 and 1971 trials, grazing was initiated as soon as observation indicated a reasonable supply of forage. This occurred on April 1 in 1969. Cool temperatures delayed plant growth in the spring of 1971 so that ample forage was not available before April 15. The 1970 trial was not initiated until May 13 following weaning of the calves at an average age of 218 days. Grazing was terminated in the fall when it became apparent that the cattle were no longer gaining weight. The date that this occurs in any year is largely dependent on the prevalence of rainfall in July, August, and September. The termination date was August 29 in 1969, October 1 in 1970, and September 17 in 1971. This resulted in a grazing period of 150 days in 1969, 141 days in 1970, and 154 days in 1971.

RESULTS

Animal Gains

1969 Trial. The average weight gains made by the yearling steers on the two grazing systems during the 150-day grazing period in 1969 are presented in Table 2. This table also shows the gains made by the cattle during various portions of the grazing period. The following important facts are demonstrated in this table:

1. Continuous grazing produced more weight gain during the 90-day period between April 1 and July 1 than was obtained from rotation grazing. During this period, the steers gained an average of 2.25 and 2.06 pounds per day, 203 and 186 pounds per head, and 244 and 223 pounds per acre on the continuous and rotational systems, respectively.
2. Rotation grazing produced more gain during the following 60-day period from July 1 to August 29 than did continuous grazing. Over this portion of the grazing season, the steers made an average gain of 1.46 and 0.55 pounds per day, 88 and 33 pounds per head, and 106 and 40 pounds per acre on the rotational and continuous systems, respectively.
3. Over the entire 150-day grazing period, the rotationally grazed steers averaged 0.25 pound per day, 38 pounds per head, and 45

pounds per acre more than the continuously grazed animals. This advantage for rotation grazing was produced during the last 60 days of the grazing season.

4. Both groups of steers made average daily gains in excess of 1.5 pounds over the 150-day grazing period. During this entire period the steers produced 329 and 284 pounds of beef gain per acre on the rotational and continuous systems, respectively.

TABLE 2.—Average Weight Gains Made by Yearling Steers Grazed on Coastal Bermudagrass During the 1969 Grazing Season (stocking rate 1.2 steers—532 lb. per acre)

		Gain, pounds		
Period	Days	Head	Daily	Acre
	—Rotation grazing—			
April 1 to June 1	60	102	1.70	123
June 1 to July 1	30	84	2.80	100
April 1 to July 1	90	186	2.06	223
July 1 to August 1	31	40	1.29	48
August 1 to August 29	29	48	1.66	58
July 1 to August 29	60	88	1.46	106
April 1 to August 29	150	274	1.82	329
	—Continuous grazing—			
April 1 to June 1	60	150	2.50	180
June 1 to July 1	30	53	1.76	64
April 1 to July 1	90	203	2.25	244
July 1 to August 1	31	8	0.26	10
August 1 to August 29	29	25	0.86	30
July 1 to August 29	60	33	0.55	40
April 1 to August 29	150	236	1.57	284
Advantage for rotation system		38*	0.25*	45*

*$P < .05$.

1970 Trial. The performance of the spring weaned calves that were grazed in the 1970 trial is shown in Table 3. These data reveal the following important facts:

1. There was no difference in the gains made by the calves on the two grazing systems during the first 48 days of grazing from May 13 to June 30. During this period, both groups of calves averaged 1.10 pounds per day, 53 pounds per head, and 148 pounds per acre.

2. Rotation grazing produced more weight gain during the 64 days between June 30 and September 2. Over this period the calves

TABLE 3.—Average Weight Gains Made by Spring Weaned Calves Grazed on Coastal Bermudagrass During the 1970 Grazing Season (Stocking rate 2.8 calves—884 lb. per acre)

		Gain, pounds		
Period	Days	Head	Daily	Acre
		—Rotation grazing—		
May 13 to June 30	48	53	1.10	148
June 30 to Sept. 2	64	46	0.72	128
Sept. 2 to Oct. 1	29	16	0.55	46
May 13 to Oct. 1	141	115	0.82	322
		—Continuous grazing—		
May 13 to June 30	48	52	1.08	147
June 30 to Sept. 2	64	32	0.50	89
Sept. 2 to Oct. 1	29	2	0.06	6
May 13 to Oct. 1	141	86	0.60	242
Advantage for rotation grazing		29*	0.22*	80*

*P<.05.

averaged 0.72 and 0.50 pound per day, 46 and 32 pounds per head, and 128 and 89 pounds per acre on the rotational and continuous systems, respectively.

3. During the month of September the continuously grazed calves made essentially no weight gain, while the rotationally grazed animals averaged 0.55 pound per day.

4. Over the entire 141-day grazing period, the rotationally grazed calves averaged 0.22 pound per day, 29 pounds per head, and 80 pounds per acre more than the continuously grazed calves. This advantage for rotation grazing was produced during that portion of the grazing period after June 30.

5. The calves in this trial gained an average of less than 1 pound per day. It is important to note, however, that 2.8 rotationally grazed calves produced 322 pounds of gain per acre. This was essentially the same gain per acre as was produced by 1.2 rotationally grazed yearling steers in the 1969 trial.

1971 Trial. The average weight gains for the yearling steers grazed on the two systems in the 1971 trial are summarized in Table 4. This summary points up the following important facts:

1. The rotationally grazed steers produced slightly larger gains during the 84 days from April 15 to July 9 than those grazed continuously. The average gains during this period were 2.25 and 2.04 pounds per day, 189 and 171 pounds per head, and 265 and 240 pounds per acre for the rotational and continuous systems, respectively. The average daily gains for the two systems were 2.75 and 2.29 pounds dur-

TABLE 4—Average Weight Gains Made by Yearling Steers Grazed on Coastal Bermudagrass During the 1971 Grazing Season (Stocking rate 1.4 steers—643 lb. per acre)

Period	Days	Gain, pounds Head	Daily	Acre
—Rotation grazing—				
April 15 to May 28	42	116	2.75	162
May 28 to July 9	42	74	1.75	103
April 15 to July 9	84	189	2.25	265
July 9 to Aug. 20	42	56	1.33	78
Aug. 20 to Sept. 17	28	28	1.02	40
July 9 to Sept. 17	70	84	1.21	118
April 15 to Sept. 17	154	274	1.78	384
—Continuous grazing—				
April 15 to May 28	42	96	2.29	134
May 28 to July 9	42	75	1.79	105
April 15 to July 9	84	171	2.04	240
July 9 to Aug. 20	42	64	1.52	89
Aug. 20 to Sept. 17	28	22	0.78	31
July 9 to Sept. 17	70	86	1.22	120
April 15 to Sept. 17	154	257	1.67	360
Advantage for rotation system		17 n.s.	0.11 n.s.	24 n.s.

n.s. Not significantly different from zero.

ing the 42-day period between the initiation of grazing on April 15 and May 28.

2. The gains for the two grazing systems were essentially equal during the 70-day period after July 9. The weight gains per acre during this period averaged 118 and 120 pounds for the rotational and continuous systems, respectively. These gains were larger than the gains produced during the latter portion of the grazing season by either system in the 1969 and 1970 trials.

3. There was a slight, but nonsignificant, advantage in weight gain produced by the rotational system over the entire 154-day grazing period. During the entire grazing season, the steers gained an average of 1.78 and 1.67 pounds per day, 274 and 257 pounds per head, and 384 and 360 pounds per acre on the rotational and continuous systems, respectively.

Changes in Animal Value

A producer who grazes stocker cattle is interested in the change in value of the animals from the beginning to the end of the grazing season. The change in animal value is influenced by both weight gain and margin. Margin is the difference between the initial and final market prices of the cattle per hundredweight. When the final price is higher than the initial price, the margin is positive and there is an increase in the value of the initial weight of the animal. When the final price is lower than the initial price, the margin is negative and there is a decrease in the value of the initial animal weight. Margin, therefore, is important to the economics of grazing stocker cattle. The influence that margin has on the change in value of the cattle is dependent upon the changes that occur in market prices from the beginning to the end of the grazing season. These changes in market price vary from year to year. Usually, however, the producer must operate on a negative margin because the market price per hundredweight often decreases as animal weight increases. Thus, if the net value of the animal is increased through the grazing season, the value of the increase in gain must more than offset the decrease in value of the initial weight resulting from negative margin.

The cattle grazed in these trials were evaluated by an order buyer at the beginning and the end of the grazing season in each year and the market price of the cattle was established. With these prices, the influences of weight gain and margin on the net changes in animal values were computed for each grazing system. These changes in value are shown in Tables 5, 6, and 7 for the 1969, 1970, and

TABLE 5.—Average Changes in Value of Yearling Steers Grazed on Coastal Bermudagrass During the 1969 Grazing Season

Item	Rotation grazing	Continuous grazing
Initial wt., lb.	445	441
Initial value/cwt., dollars	30.70	30.70
Initial value/head, dollars	136.61	135.46
Final weight, lb.	719	678
150-day gain/head, lb.	274	237
150-day gain/acre, lb.	329	284
Final value/cwt., dollars*	28.80	28.80
Final value/head, dollars	207.12	195.24
Change in value/head due to gain, dollars	78.96	68.16
Change in value/head due to margin, dollars	−8.45	−8.38
Net change in value/head, dollars	70.51	59.78
Change in value/acre due to gain, dollars	94.75	81.79
Change in value/acre due to margin, dollars	−10.14	−10.06
Net change in value/acre, dollars	84.61	71.73

*Margin: −$1.90.

1971 trials. The following important points are demonstrated in these data:

1. The margin was negative in all three years. The margin was -$1.90 in 1969, -$1.32 in 1970, and -$1.06 in 1971.
2. The negative margin was essentially equal for both grazing systems in all years.
3. The positive influence of weight gain was much more important in determining the net increase in animal value than was the negative influence of margin in the three years covered by these trials.
4. Rotation grazing produced a larger net change in value per head and per acre than continuous grazing. This was the result of the greater weight gains produced by the rotational system.

It is emphasized that the relationship between the influence of margin and weight gain in determining the net change in animal value during the grazing season is a function of market prices. The facts reported above are specific for the three years in which these trials were conducted. Any change in the relationship between the initial and final market price will result in a change in the influence of margin on the net change in animal value from the beginning to the end of the grazing season.

TABLE 6—Average Changes in Value of Spring Weaned Calves Grazed on Coastal Bermudagrass During the 1970 Grazing Season

Item	Rotation grazing	Continuous grazing
Initial wt., lb.	320	312
Initial value/cwt., dollars*	32.40	32.58
Initial value/head, dollars	103.58	101.60
Final wt., lb.	435	398
141-day gain/head, lb.	115	86
141-day gain/acre, lb.	322	242
Final value/cwt., dollars*	31.12	31.22
Final value/head, dollars	135.26	124.30
Change in value/head due to gain, dollars	35.86	27.00
Change in value/head due to margin, dollars	−4.51	−4.28
Net change in value/head, dollars	31.35	22.72
Change in value/acre due to gain, dollars	100.40	75.60
Change in value/acre due to margin, dollars	−12.62	−11.98
Net change in value/acre, dollars	87.78	63.62

*Average for all calves. Prices and margin for the four sex-weight groups were:

Group	Initial price (5-13-70)	Final price (10-1-70)	Margin
Heavy steers	$32.00	$32.50	+$0.50
Light steers	37.00	35.00	− 2.00
Heavy heifers	30.00	27.50	− 2.50
Light heifers	32.00	30.00	− 2.00
Rotation grazing	32.40	31.12	− 1.28
Continuous grazing	32.58	31.22	− 1.36

TABLE 7.—Average Changes in Value of Yearling Steers Grazed on Coastal Bermudagrass During the 1971 Grazing Season

Item	Rotation grazing	Continuous grazing
Initial wt., lb.	476	442
Initial value/cwt., dollars	34.66	34.98
Initial value/head, dollars	164.92	154.57
Final wt., lb.	750	699
154-day gain/head, lb.	274	257
154-day gain/acre, lb.	384	360
Final value/cwt., dollars*	33.54	33.98
Final value/head, dollars	251.52	237.60
Changes in value/head due to gain, dollars	91.86	87.60
Change in value/head due to margin, dollars	−5.27	−4.58
Net change in value/head, dollars	86.60	83.02
Change in value/acre due to gain, dollars	128.60	122.64
Change in value/acre due to margin, dollars	−7.38	−6.41
Net change in value/acre, dollars	121.24	116.22

*Margin −$1.12 −$1.00

Expenses, Income, and Net Returns

The average expenses, income, and net returns per animal and per acre for both grazing systems in each of the three grazing trials are presented in Tables 8, 9, and 10. The income includes both the value of the cattle at the end of the grazing season and the value of the hay harvested. The expenses include all costs involved in growing the forage, the cost of the cattle, and the interest on capital invested in cattle. The net return shown is the return to land and management. The net return figures, therefore, reflect the cost for the use of land. The data presented in these tables demonstrate the following important findings:

1. In each of the three years, the expenses were essentially equal for the two grazing systems. The principal differences were the cost item of $1 per acre per year charged for additional fencing, water facilities, and labor required for the rotation grazing system, the cost of harvesting hay, and the slightly heavier initial weight of the rotationally grazed cattle.

2. The costs per pound of gain in the 1969 trial were 19.7¢ and 22.5¢ for rotation and continuous grazing, respectively. In 1970, these costs were 12.5¢ and 13.2¢ for the two grazing systems. In 1971, one pound of gain was produced at a cost of 8.3¢ under both systems. In calculating these costs per pound of gain, the expense of producing and harvesting the hay was included.

3. The returns from the sale of cattle were larger for the

TABLE 8.—Expenses, Income, and Net Returns to Land and Management for Rotation and Continuous Grazing for the 1969 Trial with Yearling Steers

	Rotation grazing		Continuous grazing	
	Per animal	Per acre	Per animal	Per acre
Expenses				
300 lb. 0-20-20 @$70/ton	$ 8.75	$ 10.50	$ 8.75	$ 10.50
1,000 lb. 33- 0- 0 @$50/ton	20.83	25.00	20.83	25.00
Fertilizer application	5.00	6.00	5.00	6.00
Additional fencing, water, labor	0.83	1.00	—	—
Initial cost of steers @$30.70	136.61	163.93	135.46	162.55
Interest on investment in calves @6%	3.36	4.03	3.34	4.00
Marketing costs on cattle	8.78	10.54	8.22	9.86
Harvesting hay @$10/ton	6.66	8.00	7.08	8.50
Total expenses	$190.82	$229.00	$188.68	$226.41
Expenses less calf costs	$ 54.21	$ 65.07	$ 53.22	$ 63.86
Income				
Rotation grazing				
Sale of steers @$28.80	$207.12	$248.54		
0.80 ton hay @$20/ton	13.33	16.00		
Continuous grazing				
Sale of steers @$28.80			$195.24	$234.28
0.85 ton hay @$20/ton			14.16	17.00
Total returns	$220.45	$264.54	$209.40	$251.28
Net returns to land and management	$ 29.63	$ 35.54	$ 20.72	$ 24.87

rotational system in all three years. This was the result of the larger weight gains produced by rotation grazing.

4. More hay was harvested from the pasture that was grazed rotationally in two of the three years. This was primarily due to the fact that the grazing and haying could be managed with more precision under the rotational system.

5. Rotation grazing produced $11.05 per head and $13.26 per acre more income than continuous grazing in 1969. The advantage in income for rotation grazing in 1970 was $16.31 per head and $44.71 per acre. In 1971, the income produced by rotation grazing was $24.92 per head and $34.88 per acre greater than the income from continuous grazing.

6. The differences between the income and expenses are shown in the tables as net returns to land and management. In 1969, the net returns were $29.63 and $20.72 per head and $35.54 and $24.87 per acre for the rotational and continuous systems, respectively. The two grazing systems produced net returns of $24.07 and $12.69 per head and $66.43 and $35.57 per acre in 1970. In 1971, the net returns from rotation grazing were $88.00 per head and $107.89 per acre, while

TABLE 9.—Expenses, Income, and Net Returns to Land and Management for Rotation and Continuous Grazing for the 1970 Trial with Spring Weaned Calves

	Rotation grazing		Continuous grazing	
	Per animal	Per acre	Per animal	Per acre
Expenses				
300 lb. 0-20-20 @$70/ton	$ 3.75	$ 10.50	$ 3.75	$ 10.50
400 lb. 33-0-0 @$50/ton	3.57	10.00	3.57	10.00
Fertilizer application	1.07	3.00	1.07	3.00
Additional fencing, water, labor	0.36	1.00	—	—
Initial cost of calves*	103.58	290.04	101.60	284.47
Interest on investment in calves @6%	2.41	6.76	2.31	6.48
Harvesting hay @$10/ton	3.21	9.00	0.71	2.00
Total expenses	$117.95	$330.30	$113.02	$316.45
Expenses less calf costs	$ 14.37	$ 40.26	$ 11.42	$ 31.98
Income				
Rotation grazing				
Sale of calves*	$135.60	$378.73		
0.9 ton hay @$20/ton	6.42	18.00		
Continuous grazing				
Sale of calves*			$124.29	$348.02
0.2 ton hay @$20/ton			1.42	4.00
Total returns	$142.02	$396.73	$125.71	$352.02
Net Returns to land and management	$ 24.07	$ 66.43	$ 12.69	$ 35.57

*Prices per pound:	Initial (5/13/70)	Final (10/1/70)
Heavy steers	32¢	32.5¢
Light steers	37¢	35.0¢
Heavy heifers	30¢	27.5¢
Light heifers	32¢	30.0¢

the net returns from the continuous system were $74.91 per head and $96.53 per acre. While rotation grazing produced greater returns to land and management than continuous grazing in all years, it is important to note that continuous grazing produced substantial returns.

The financial data presented for the three trials in Tables 8, 9, and 10 are summarized in Table 11. The values shown in Table 11 are averages of the three years. These values reflect the following important facts:

1. A somewhat larger investment was required for the rotational system. The expenses per acre, including animal costs, averaged $279.18 for rotation grazing and $265.86 for continuous grazing, $13.32 more for rotation grazing. A part of this difference was due to the slightly heavier initial weight of the animals used on the rotational system.
2. The net returns to land and management per acre averaged $69.94 and $52.32 for the rotational and continuous systems, re-

TABLE 10.—Expenses, Income, and Net Returns to Land and Management for Yearling Steers Grazed on Coastal Bermudagrass During the 1971 Grazing Season

	Rotation grazing		Continuous grazing	
	Head	Acre	Head	Acre
Expenses				
300 lb. 0-20-20 @$70/ton	$ 7.50	$ 10.50	$ 7.50	$ 10.50
400 lb. 33- 0- 0 @$50/ton	7.14	10.00	7.14	10.00
Fertilizer application	2.14	3.00	2.14	3.00
Additional fencing, water, labor	0.71	1.00	—	—
Initial cost of steers[1]	164.92	230.88	154.57	216.40
Interest on investment in calves @6%	4.18	5.85	3.96	5.54
Harvesting hay @$10/ton	1.21	17.00	0.66	9.27
Total expenses	$187.80	$278.23	$175.97	$254.71
Expenses less steer costs	$ 23.00	$ 47.35	$ 21.40	$ 38.31
Income				
Rotation grazing				
Sale of steers[2]	$251.52	$352.12		
1.7 ton hay @$20/ton	24.28	34.00		
Continuous grazing				
Sale of steers[2]			$237.60	$332.64
0.93 ton hay @$20/ton			13.28	18.60
Total returns	$275.80	$386.12	$250.88	$351.24
Returns to land and management	$ 88.00	$107.89	$ 74.91	$ 96.53
[1]Avg. initial price/cwt.	$ 34.66		$ 34.98	
[2]Avg. sale price/cwt.	$ 33.54		$ 33.98	

TABLE 11.—Average Expenses, Income, Net Returns to Land and Management, and Cost Per Pound of Gain for Rotation and Continuous Grazing Over the Three Trials in 1969, 1970, and 1971

	Per head			Per acre		
	Rotation	Continuous	Difference	Rotation	Continuous	Difference
Total expenses	$165.52	$159.22	$ 6.30	$279.18	$265.86	$ 13.32
Income—						
Cattle	$198.08	$185.71	$ 12.37	$326.46	$304.98	$ 21.48
Hay	14.68	9.62	5.06	22.66	13.20	9.46
Total	$212.76	$195.33	$ 17.43	$349.12	$318.18	$ 30.94
Net returns to land and management	$ 47.24	$ 36.11	$ 11.13	$ 69.94	$ 52.32	$ 17.62
Expenses less animal costs	$ 30.52	$ 28.68	$ 1.84	$ 50.89	$ 44.72	$ 6.17
Weight gain, lb.	221	193	28	345	295	50
Cost/lb. gain	13.8¢	14.8¢	1¢			

spectively. These returns gave rotation grazing an advantage of $11.13 per head and $17.62 per acre per year.

3. The cost of producing one pound of weight gain averaged 13.8¢ for rotation grazing and 14.8¢ for continuous grazing.

4. Over the three years reported here, the rotational system produced a total of 1,035 pounds of weight gain per acre while the continuous system produced a total of 885 pounds. The total returns to land and management over the three-year period were $209.82 and $156.96 per acre for rotation and continuous grazing, respectively.

DISCUSSION

The results reported in the previous section from three grazing trials with stocker cattle on Coastal bermudagrass pastures demonstrate two facts that are important to Louisiana cattle producers. First, with a well-managed forage production and utilization program, Coastal bermudagrass produced satisfactory and profitable weight gains on stocker cattle—both calves and yearlings. Second, the rotation grazing system used in these trials produced larger and more profitable weight gains than continuous grazing, primarily because rotation grazing resulted in greater weight gains after July 1. The following discussion may explain some of the reasons why a sound forage management program is necessary to more nearly attain optimum utilization of the forage producing potential of Coastal bermudagrass.

Coastal bermudagrass is a warm-season perennial plant. It begins its growth as temperature begins to rise in the spring and, with an adequate supply of plant food, makes very vigorous growth during the spring and early summer. As the summer season progresses, there is a natural tendency for the plants to mature, resulting in a decrease in the quantity and quality of forage produced and, consequently, in a reduction in the weight gains of grazing animals. This maturing process can not be eliminated from the growth pattern of the plants. It was postulated, however, that management practices that would tend to keep the plants in a young, immature state of growth would delay the natural plant maturity and cause the growth of more desirable forage. Experience with haymaking from Coastal bermudagrass has shown this to be true. It was also postulated that delaying the maturing process in the Coastal bermudagrass plants would also tend to cause more desirable forage to be grown later in the growing season.

The results of the grazing trials reported here suggest that the rotation grazing system used, together with more precise haying, may have delayed the maturing process in the plants. The cattle grazed under this system made significantly greater weight gains in two of the three trials. The larger weight gains made by the rotationally grazed cattle occurred during the period after July 1. The concentration of a larger number of cattle on a given area of Coastal bermudagrass probably resulted in a more complete utilization of the vegetative parts of the plants. The 10-day regrowth period following close grazing allowed the plants to recuperate and seemingly induced the production of more young, immature forage than was produced by the continuously grazed plants.

If the maximum forage producing potential of Coastal bermudagrass is to be utilized, it is necessary to apply nitrogen fertilizer periodically during the growing season. The application of nitrogen fertilizer stimulates the growth of the plants and an excessive amount of forage may be produced, especially during the first half of the growing season. If this forage is not removed, the plants will go into the maturing stage, seed heads will be produced, the leaves near the ground will begin to die, and forage quality will become low. Good management may require removal of the excess forage in the form of hay. The rotation grazing system lends itself to efficient hay making. When it becomes apparent that excess forage is being produced, the grazing can be confined to less than four paddocks. This allows excess forage in the paddocks being grazed to be controlled by grazing and allows the growth of enough high quality hay to justify harvesting in the ungrazed paddocks. This precision of hay making is not possible under a continuous grazing system. This fact was obvious in the data from these grazing trials, which show that more than twice as much hay was harvested under the rotation grazing system. This finding may indicate the need for smaller, but more frequent, applications of nitrogen fertilizer. It may also indicate the need for a heavier stocking rate of cattle to control the production of excess forage.

While Coastal bermudagrass is more resistant to the effects of dry weather than most warm-season perennials, the plants do tend to decrease vegetative growth and go into the maturing stage in response to insufficient moisture. In North Central Louisiana, the rainfall during the summer growing season is often below average due to insufficient rainfall during July, August, and September. This fact is shown in Table 12, which compares the average monthly rainfall for the 20-year period immediately prior to 1969 and the actual monthly rainfall for 1969, 1970, and 1971. Rainfall during the months of July, August, and September was below average in 1969 and 1970. In the grazing trials in these two years, rotationally grazed cattle produced greater weight gains during these three months than continuously grazed cattle. The differences in weight gains between the two grazing systems can not be attributed to weather. It is postulated

TABLE 12.—Twenty-Year Average and 1969, 1970, and 1971 Rainfall for the Spring and Summer Grazing Season

	Rainfall, inches			
Month	20-year avg., 1950-69	1969	1970	1971
April	5.58	4.53	5.33	1.45
May	5.32	3.74	6.82	4.30
June	3.62	1.03	2.23	2.69
July	4.36	1.77	4.01	7.65
August	3.26	1.66	1.76	5.22
September	4.20	1.26	2.77	4.16
Total	26.34	13.99	22.92	25.47

that the greater weight gains of the rotationally grazed cattle resulted from more or better quality forage. The plants being grazed under the rotational system seemed to suffer less stress from marginal moisture. This may have been caused by the 10-day period of regrowth free from grazing. It was observed during August and September in both 1969 and 1970 that most of the new leaf growth on the continuously grazed plants was generally less than one inch in length. During this same period, it was observed that the rotationally grazed plants had produced new leaves that were two to three inches in length by the end of the 10-day regrowth period. The deficiency in new leaf growth on the plants being grazed continuously likely was due to the uninterrupted grazing pressure on plants growing under physiological stress since all other environmental factors were as nearly the same as could be established.

Table 12 also shows that the rainfall during July, August, and September of 1971 was near or above the 20-year average for these months. There was no significant difference in the weight gain of the cattle on the two grazing systems in 1971. These observations seem to indicate that when there is ample moisture during this part of the summer grazing season, the continuously grazed plants are not subjected to physiological stress and the maturing process is delayed. The results obtained in the 1971 trial may indicate that rotation grazing is superior to the continuous system only in years when rainfall in July and August is deficient. Weather records at this station show, however, that July and August rainfall was below the 20-year 1950-69 average more than half those years. Rotation grazing seems to be good insurance against unprofitable weight gains on stocker cattle in years with insufficient late summer rainfall.

SUMMARY

Three trials were conducted grazing stocker calves and yearlings on Coastal bermudagrass pastures during the 1969, 1970, and 1971 spring and summer grazing season. The purposes of the trials were to evaluate Coastal bermudagrass as a forage plant for stocker cattle and to compare the weight gains and returns produced by continuous and rotation grazing. Under the continuous system all the forage in the pasture was available for grazing at all times. In the rotational system used, the pasture was crossfenced into four paddocks of equal size. The cattle were grazed on only one paddock at a given time and were systematically moved from paddock to paddock so that each was grazed 3 days and allowed 10 days for regrowth. The same stocking rates were used on the two grazing systems.

The results obtained from the three grazing trials show the following important findings:

1. Rotation grazing is superior to continuous grazing over a period of several years. In two of the three years covered by this study, the grazing system utilizing four paddocks and a three-day-on–ten-day-off rotation produced larger animal gains and a greater net return than was obtained using similar cattle on the continuous system. The continuous system produced equal or larger weight gains before July 1 in all three years but was definitely inferior after July 1 in two of the three years. Rainfall after July 1 in these two years was below average. During the third year, when rainfall after July 1 was above average, there was no significant difference in seasonlong animal gains for the two grazing systems.

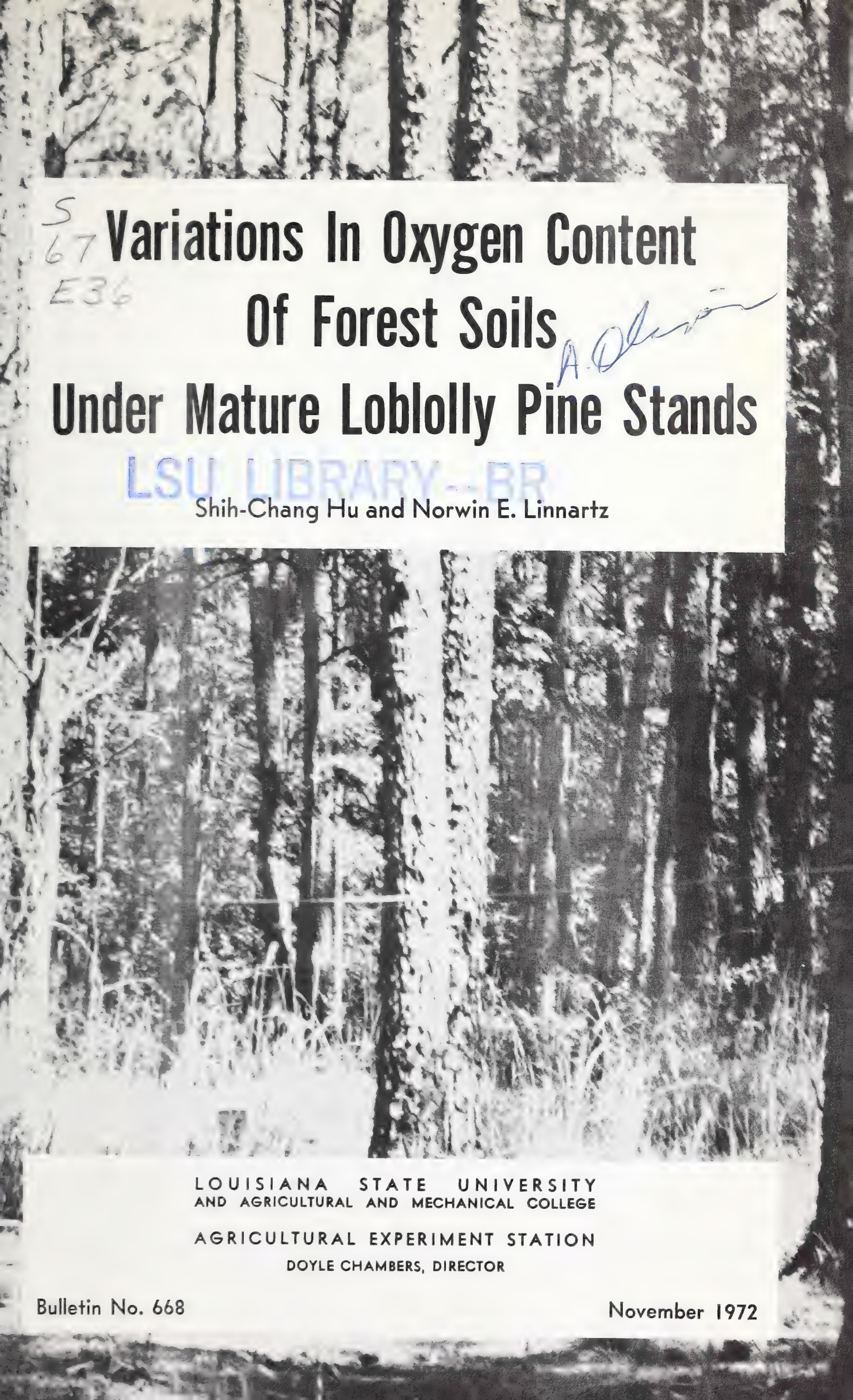
2. The three-year average weight gains per acre were 345 pounds and 295 pounds for the rotational and continuous grazing systems, respectively. The average weight gains per animal were 221 and 193 pounds.

3. The cost of producing one pound of gain averaged 13.8¢ for rotation grazing and 14.8¢ for continuous grazing over the three trials. The cost per pound of gain was largely determined by the amount of gain produced per acre. This cost was greatest in 1969, when animal gain was smallest. In 1971, when the largest animal gain per acre was obtained, the cost of producing one pound of gain was 8.3¢ for both grazing systems. These production costs compare favorably with the gain costs for similar cattle grazed on winter pastures.

4. The average net return to land and management over the

three years was $69.94 per acre for rotation grazing and $52.32 for continuous grazing.

5. These grazing trials indicate that the grazing of Coastal bermudagrass with stocker cattle can be profitable and should be considered by Louisiana landowners as an efficient land use alternative.



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Variations In Oxygen Content Of Forest Soils Under Mature Loblolly Pine Stands

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Variations in Oxygen Content Of Forest Soils Under Mature Loblolly Pine Stands

SHIH-CHANG HU AND NORWIN E. LINNARTZ[1]

Introduction

The importance of soil oxygen content to root growth and tree development is obvious. Numerous reports have shown that a deficiency of soil oxygen decreases respiratory activity, reduces water and nutrient absorption, influences root morphology and disease incidence, and reduces rooting depth and plant growth of various plants (Harris and Van Bavel 1957a, 1957b; Kohnke 1968; Kramer 1949, 1950, 1969; Lawton 1945; Letey et al. 1962; Patrick et al. 1969; Patrick 1971; Williamson 1964; and others). But the soil oxygen required for optimum root growth and plant development varies greatly with species and age of the plant (Leyton and Rousseau 1958). Some species can survive with only 1 or 2 percent oxygen (Cannon 1925), but more than 10 percent and less than 21 percent is required by most plants for good growth (Boynton and Reuther 1938, Kohnke 1968, Kramer 1969, and Leyton and Rousseau 1958).

Many reports have been published on the relationship of soil oxygen to root growth and plant development, but most of this research was done with herbaceous species grown in sand or solution cultures; very little has been done with tree species. As a result, much of the information concerning the importance of soil oxygen to tree growth is based on inference rather than quantitative data obtained from the field. Despite the lack of field verification, the large amount of quantitative information concerning soil oxygen and crop growth seems to lead to the conclusion that soil oxygen is one of the most important factors affecting tree growth and timber production.

The oxygen content in soil air varies with season and soil depth. In general, oxygen content in soil air is low in winter and early spring and increases as the season progresses (Boynton and Reuther 1939), and the content of soil oxygen decreases with increases in soil depth (Patrick et al. 1969).

It has been reported also that soil physical properties, such as moisture content, compaction, texture, and structure, affect the oxygen content in the soil profile (Hopkins and Patrick 1969, Patrick 1971, Russell 1952); but there is a surprising lack of quantitative data to prove these relalationships. More extensive experiments are needed and more basic information must be obtained directly from the forests to explain satisfactorily how soil oxygen content limits root growth and tree development.

---

[1] Former Graduate Research Assistant and Professor, respectively, School of Forestry and Wildlife Management.

The main purposes of this study were to measure the oxygen content in several soil types under mature loblolly pine (*Pinus taeda* L.) trees and to find out how soil oxygen changes with season, with soil depth, and with depth to the water table. An attempt was also made to relate the soil oxygen content to such soil physical properties as moisture content, texture, structure, porosity and bulk density. The results of this study provide basic information about the root growth conditions of trees and thus should be useful to our understanding of natural soil productivity for timber production.

Methods and Procedures

Location and Description of Study Area

In 1967 the Louisiana Agricultural Experiment Station, through the School of Forestry and Wildlife Management, began a research project involving 20 quarter-acre plots at Louisiana State University's Lee Memorial Forest near Franklinton in Washington Parish, Louisiana. The circular plots, numbered 1 through 20, were established at different locations and on different soil types. The main objectives were to study the rooting depth of mature southern pine trees and determine soil properties which limit deeper penetration of roots within the soil profile. Related to these objectives was the study of variations in soil oxygen, which is the subject of this report.

Only 9 of the 20 plots (Plots 1, 4, 5, 7, 9, 10, 17, 18, and 20) were used for the study of soil oxygen. These plots are located in even-aged loblolly pine stands ranging in density from 65 to 127 ft^2 of basal area per acre. Trees on the plots were from 39 to 48 years old. The stand characteristics, soils, and depths at which oxygen was measured in each plot are listed in Table 1.

The soils on the nine study plots are representative of the uplands and minor stream bottoms of the Coastal Plain. The soils are loamy in texture and range from the poorly drained Bibb (Typic Haplaquent) and Myatt (Typic Ochraquult) to the well-drained Ruston (Typic Paleudult). The depths at which the oxygen content of the soil air was measured in each plot were determined on the basis of previously measured soil-moisture changes; oxygen measurements were made at those depths where appreciable changes in soil moisture had occurred during the previous 2 years.

So far as is known, none of the study plots had ever been in cultivation. The original forest stand—probably pure longleaf pine (*Pinus palustris* Mill.) on the uplands and loblolly pine mixed with hardwoods on the wetter sites—was clearcut in the early 1920's. Subsequently, much

Table 1.—Stand characteristics, soils, and depths at which soil oxygen content was measured in each plot

Plot number	Basal area per acre	Average tree age	Site index[a]	Soil classification[b]	Measurement depths
	(Ft.^{2})	(Years)			(Feet)
1	65	42	98	Strough vfsl (Fragiaquic Paleudult)	1, 2, 3, 4
4	101	41	98	Bowie fsl (Plinthic Paleudult)	1, 2, 3, 4
5	113	48	107	Bibb sil (Typic Haplaquent)	1, 2, 3, 4
7	127	42	100	Lexington sil (Ultic Paleudalf)	1, 3, 5, 7
9	118	39	100	Ruston sl (Typic Paleudult)	1, 2, 3, 4, 5, 6, 7
10	98	39	98	Ruston sl (Typic Paleudult)	1, 2, 4, 6
17	109	43	115	Bowie l (Plinthic Paleudult)	1, 2, 3, 4
18	114	39	113	Myatt vfsl (Typic Ochraquult)	1, 2, 3, 4
20	115	42	118	Stough vsfl (Fragiaquic Paleudult)	1, 2, 3, 4

[a] Based on mean height (in feet) of dominant and codominant trees at age 50.

[b] Soils on the plots were classified by Sherman A. Lytle, soil scientist, Louisiana Agricultural Experiment Station. Letters after soil series names represent soil texture: sil = silt loam, sl = sandy loam, fsl = fine sandy loam, vfsl = very fine sandy loam, l = loam.

of the university forest became reestablished to loblolly pine with the typical hardwood component. When the plots were established in 1967, the hardwood trees were cut or injected with a herbicide after which the hardwood sprouts were controlled by periodic herbicide application with a mist blower. An aluminum access tube for soil moisture measurements was installed to a depth of 20 feet in each of the plots when they were first established.

Collection of Field Data

Soil oxygen.—The method used to measure soil oxygen content in this study was similar to the method used by Patrick et al. (1969) for sampling and analyzing oxygen content in soil profiles in the sugarcane area of Louisiana. This method involved establishment of a permanent air reservoir in the soil profile at each depth selected for oxygen measurements. These reservoirs were sealed off from the atmosphere and air in the reservoir was allowed to come to equilibrium with the soil air. Samples of soil air (12 to 20 cc.) were drawn into an oxygen analyzer cell and the oxygen content was read directly on an oxygen meter.

Soil oxygen content was measured at 2-week intervals at each soil depth in three replicated installations per plot. Measurements were started on April 4, 1970, and continued until April 20, 1971, to determine the seasonal pattern of soil oxygen changes under the mature loblolly pine trees.

Soil moisture.—Soil moisture contents were measured weekly with a neutron moisture probe and portable scaler. Only soil moisture measurements collected from the same depths and on about the same dates as the oxygen measurements were used to determine the correlation between oxygen content and moisture content in the soil.

Water table.—Sections of drainpipe 5 feet long with 4-inch inside diameter were installed in the soil in six of the nine plots (1, 4, 5, 17, 18 and 20) to measure fluctuations in the water table. These pipes were inserted to a depth of 4½ feet in October 1970. The tops were covered with plastic to prevent direct entrance of rain into the pipes. Every 2 weeks the depth to the water table was measured with a tape so the presence of free water could be related to the oxygen content in the soil profile above the water table.

Collection and Analyses of Soil Samples

Two soil samples were collected from each soil depth in each plot in November 1970. In order to determine the bulk density and porosity of the soil, cores of undisturbed soil approximately 2 inches in diameter and 3 inches thick with a volume of 200 cm^3 were collected with a soil core-sampler similar to that developed by Jamison, Weaver, and Reed (1950).

The sample cores were saturated in a water bath and then transferred to a tension table similar to that developed by Leamer and Shaw (1941) and described by Hoover, Olson, and Metz (1954).

The soil-sample cores were drained on the tension table at 0 and 60 cm of water tension and were weighed after about 8 hours at each tension. In order to get the oven-dry weight of the soil samples, the sample cores were put in the oven at 105° C for more than 24 hours.

The bulk density (volume weight) of each core sample was calculated by the procedures described by Baver (1956). The total porosity of each core was determined from the following equation:

$$\text{Total Porosity (\%)} = \frac{\text{Saturated weight} - \text{Oven-dry weight}}{\text{Volume of core}} \times 100$$

The non-capillary porosity was considered equal to the volume of water drawn from the cores by 60 cm of water tension. The difference between total and non-capillary porosity is the capillary porosity.

The Bouyoucos method as modified by Patrick (1958) was used for mechanical analyses of soil samples. The texture of each soil sample was determined from the calculated sand, silt, and clay percentages by using the standard texture triangle (Soil Survey Staff 1951).

Statistical Analyses of Data

The effects of changes in season and soil depth on oxygen content of the soil air were tested by analysis of variance. Linear correlation analyses were used to evaluate the relationship between oxygen content and soil moisture, texture, porosity, and bulk density.

Results and Discussion

Basic plot data on biweekly measurements of soil oxygen content during the period of April 4, 1970, through April 20, 1971, are presented in the thesis by Hu (1971). Significant results drawn from these basic data are summarized and discussed in the following sections.

Seasonal Variations in Oxygen Content

The biweekly changes in oxygen content of the soils in four of the nine plots are illustrated in Figures 1, 2, 3, and 4. The contents of soil oxygen in these plots are representative of those measured in the other plots. The oxygen content in these forest soils was normally lower in winter and in early spring (December to March) and was higher during summer and in the first part of autumn (June to October). Also, the soil oxygen content increased gradually as the growing season progressed. Similar results were reported for other soils by Boynton and Reuther (1938, 1939), Patrick et al. (1969), Russell (1952), and Unger and Danielson (1965).

In most cases, the oxygen content in the upper 2 feet of soil was around 20 percent throughout the growing season (April through October). In contrast, the oxygen content below 2 feet varied from less than 10 to about 16 percent during this period of time. However, well-drained soils (e.g. Plot 9, Figure 3) exhibited less variation in oxygen level during the year.

The biweekly variations in soil oxygen contents were tested by analysis of variance and proved to be statistically significant in every plot except in the case of the bottom slope positions in Plots 10 and 17. This may be explained by the presence of a high water table in these two plots so that the bottom of the slope was saturated with free water most of the year. The oxygen content of free water, either in or on the surface of the soil, is very low, ranging from 4 to 8 ppm in the water tables encountered in this study and from 3.7 to 6 ppm in case of surface water (Kennedy 1969). Thus, the oxygen content in free water is much less than 1 percent and therefore was represented by 0.9 percent oxygen in the statistical analyses. Because the soils at the bottom of the slope in both Plots 10 and 17 were saturated by free water most of the year, results of the statistical analysis of biweekly variations should be nonsignificant.

The curves in Figures 1 through 4 also indicate that the oxygen contents began to increase in April and reached their highest values during

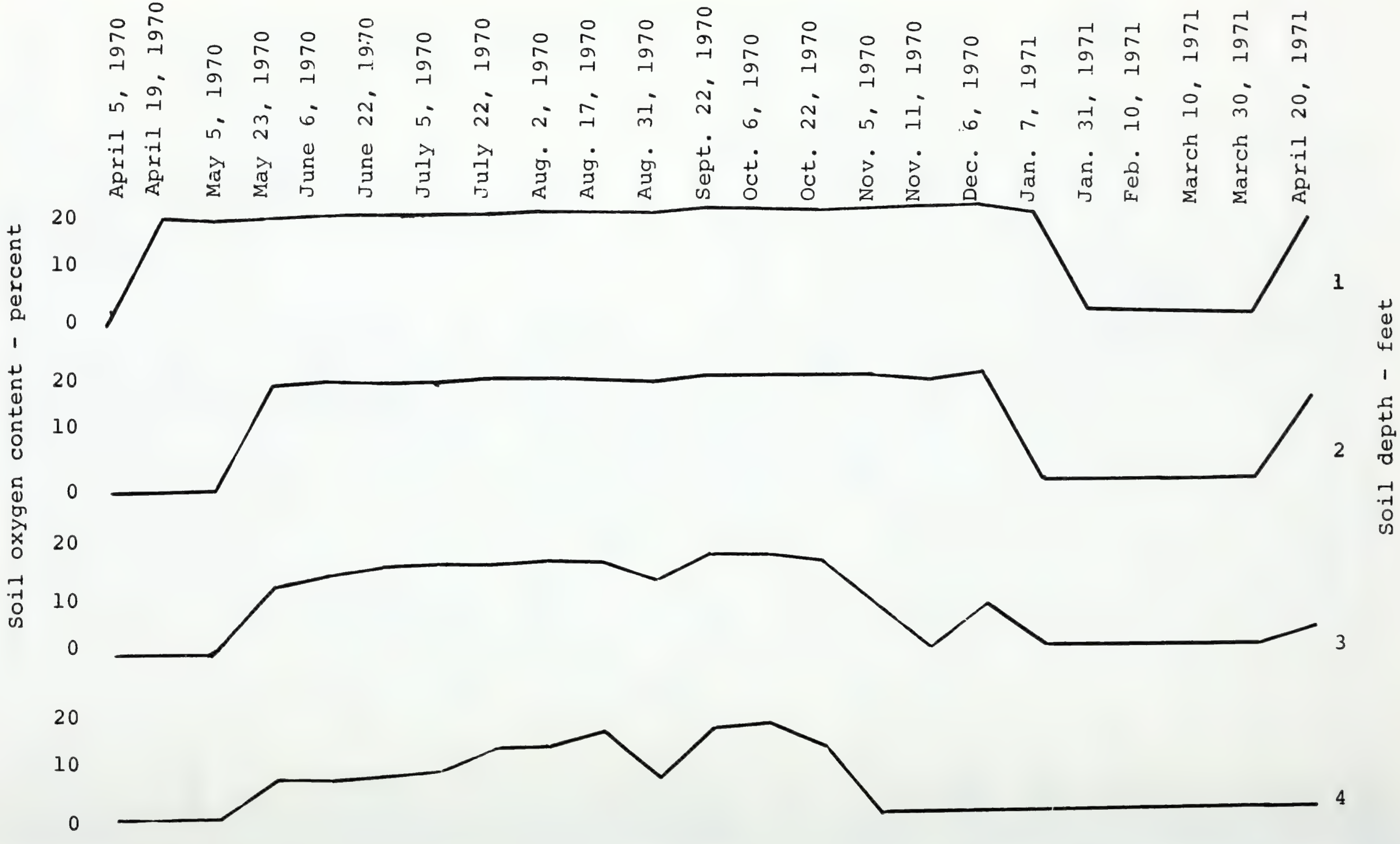

Figure 1.—Biweekly changes in soil oxygen content in Plot No. 1.

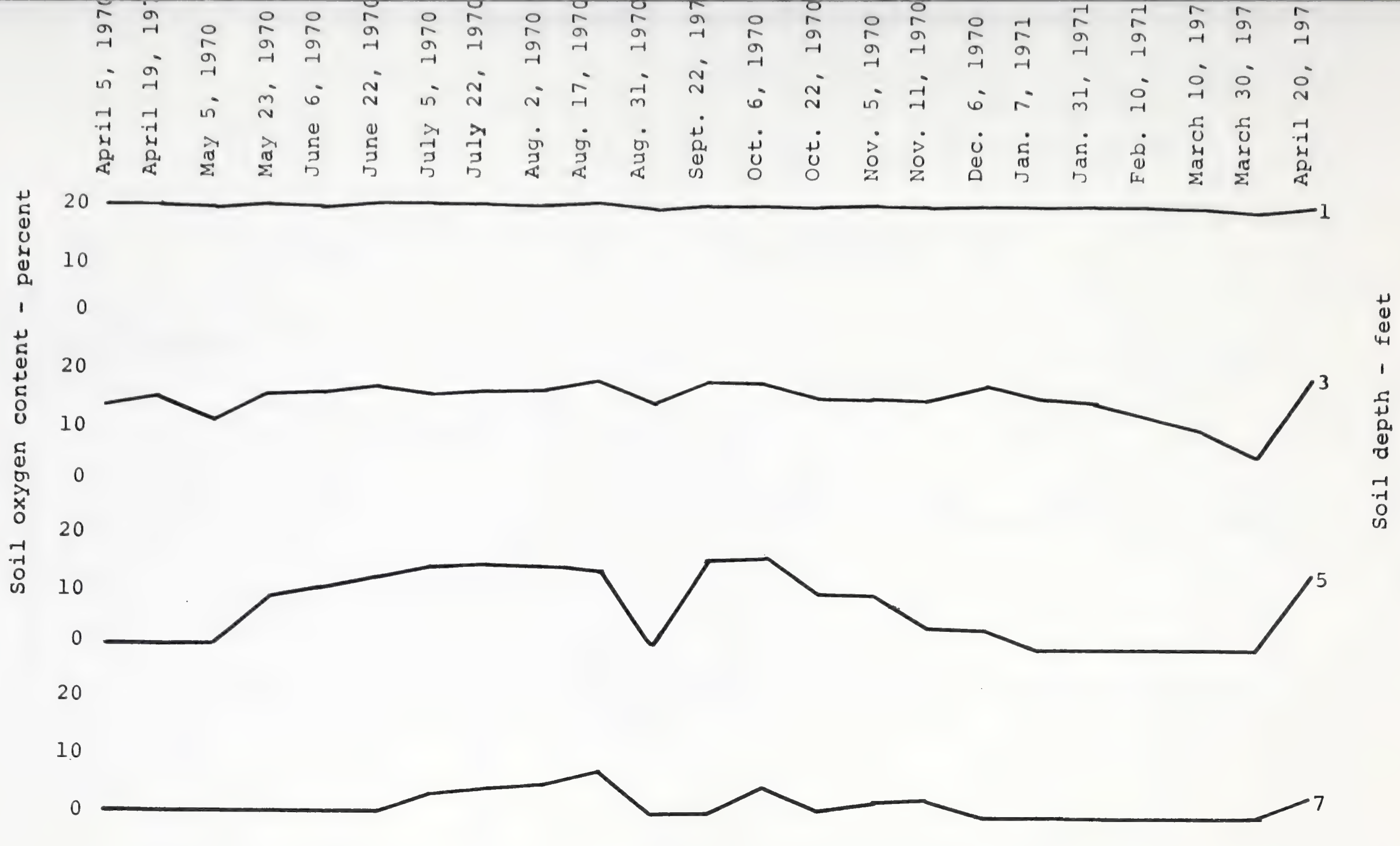

Figure 2.–Biweekly changes in soil oxygen content in Plot No. 7.

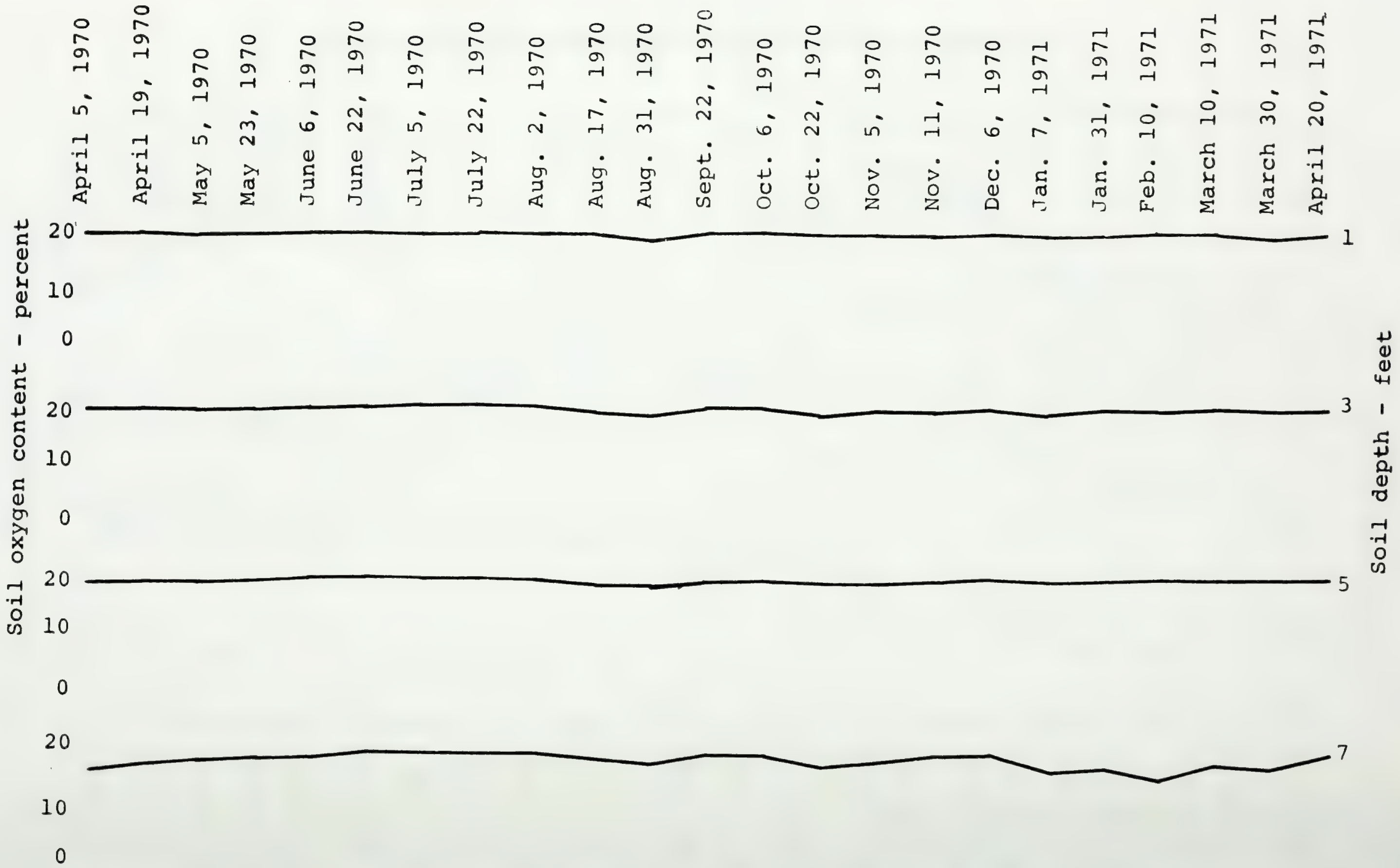

Figure 3.—Biweekly changes in soil oxygen content in Plot No. 9.

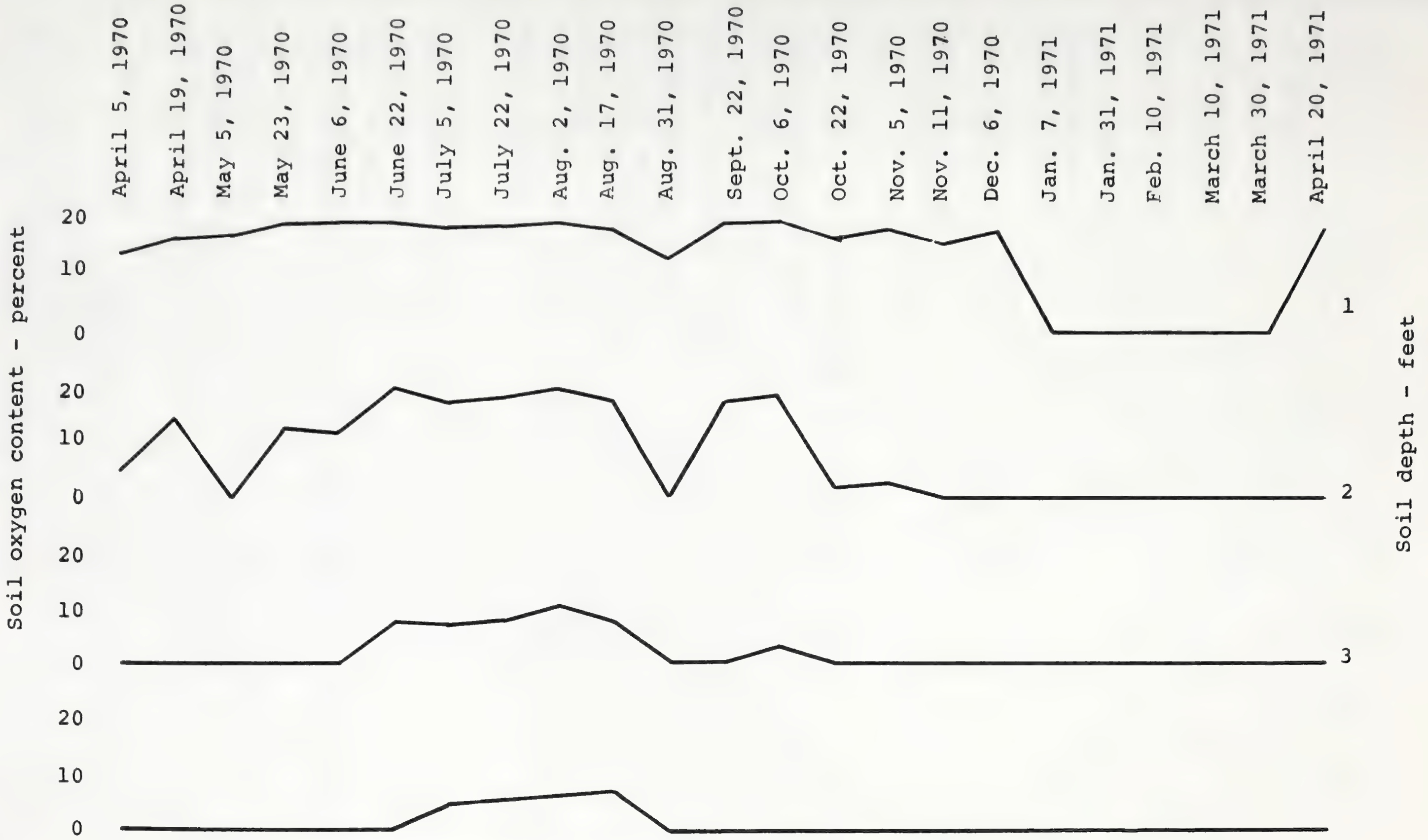

Figure 4.–Biweekly changes in soil oxygen content in Plot No. 18.

the summer and then declined again until they reached their lowest values during the winter months. This may be explained by changes in soil moisture and temperature. With initiation of growth processes, trees begin very active transpiration in April. As a result, water tables decline and soil moisture also begins to decrease. As soil moisture decreases, the air space for gaseous exchange increases, which will in turn cause an increase in oxygen in the soil. Air and soil temperature changes may also increase the rate of oxygen diffusion, thereby contributing to the increase of oxygen in the soil profile. All the factors that influence the seasonal variation of soil oxygen will have their maximum effects during the summer. As the end of the growing season approaches, transpirational losses become less, soil moisture increases, and temperatures decrease. The end result is a decline in oxygen levels in the soil.

Seasonal variations of soil oxygen were more marked at the lower depths (subsoils) and in low sites such as Plots 1 and 18 (Figures 1 and 4). This may be due to greater variations of soil moisture in the subsoils and to fluctuations in the water table levels in low sites.

Variations in Oxygen Content with Soil Depth

As would be expected, the oxygen content in these forest soils normally decreased with soil depth (Figures 5, 6, and 7). Data for the other plots followed a similar pattern (see Hu 1971). There was a decrease in oxygen content in these soils with depth throughout the whole year in every plot, as well as a marked decline in soil oxygen content with soil depth during the winter months. This is in general agreement with all the early reports (Boynton and Reuther 1938 and 1939, Patrick et al. 1969, Russell 1952, Unger and Danielson 1965, and others). The oxygen content changed only slightly with depth in a dry soil such as in Plot 9 (Figure 6), but changed greatly in the wet plots such as are depicted in Figures 5 and 7.

In every plot, changes in oxygen content with soil depth were shown to be highly significant by analysis of variance. In low site soils (Figures 5 and 7), the average oxygen content for the year was around 15 percent in the upper foot but only about 5 percent or less at the 4-foot depth. But in well-drained soils (Figure 6), the oxygen content was around 15 percent as deep as 7 feet, even in late winter.

As might be expected, topsoils are usually higher in oxygen content than are subsoils. The non-capillary porosity in topsoils is normally higher than in subsoils, and higher moisture contents in subsoils, especially if a high water table is present, also contribute to the reduction of oxygen content in the subsoils.

Effect of Rainfall on Soil Oxygen Content

The oxygen contents in the soils on every plot dropped sharply from the normal several times during the year of measurements. These sharp reductions in oxygen content were likely due to relatively large amounts

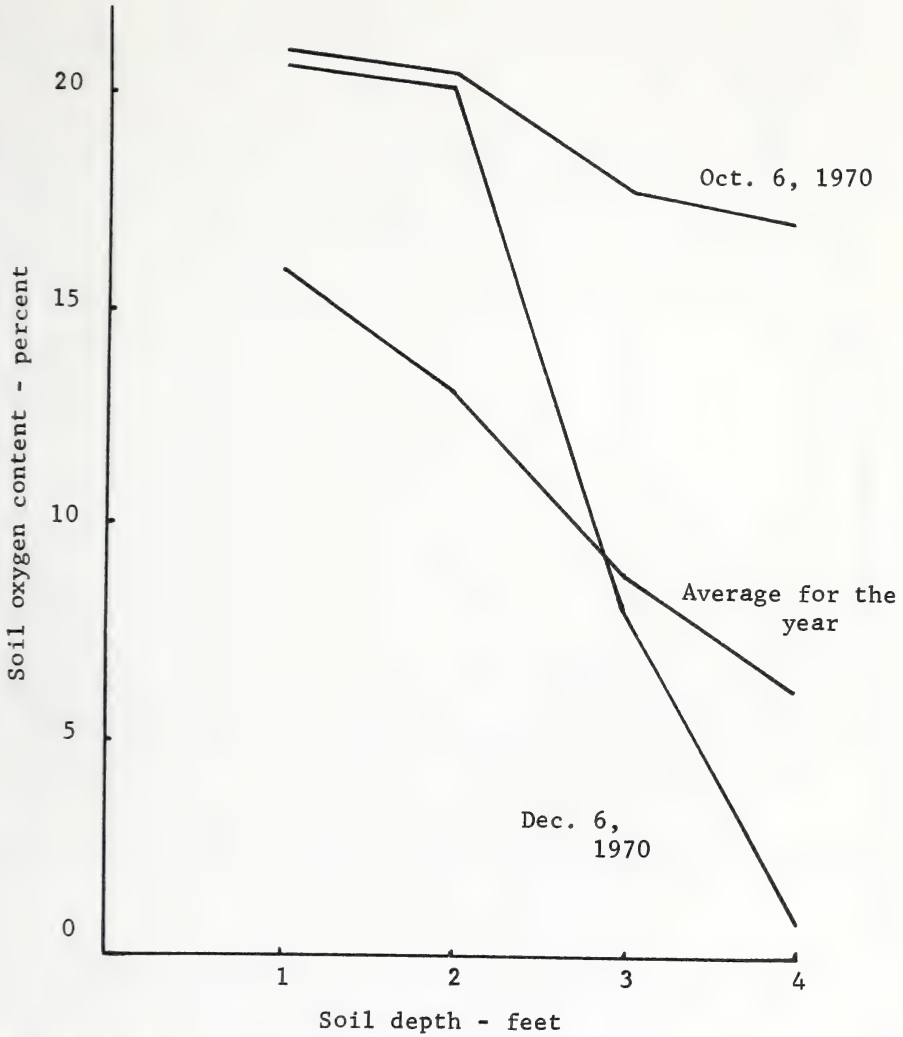

Figure 5.—Changes in soil oxygen content with soil depth in Plot No. 1.

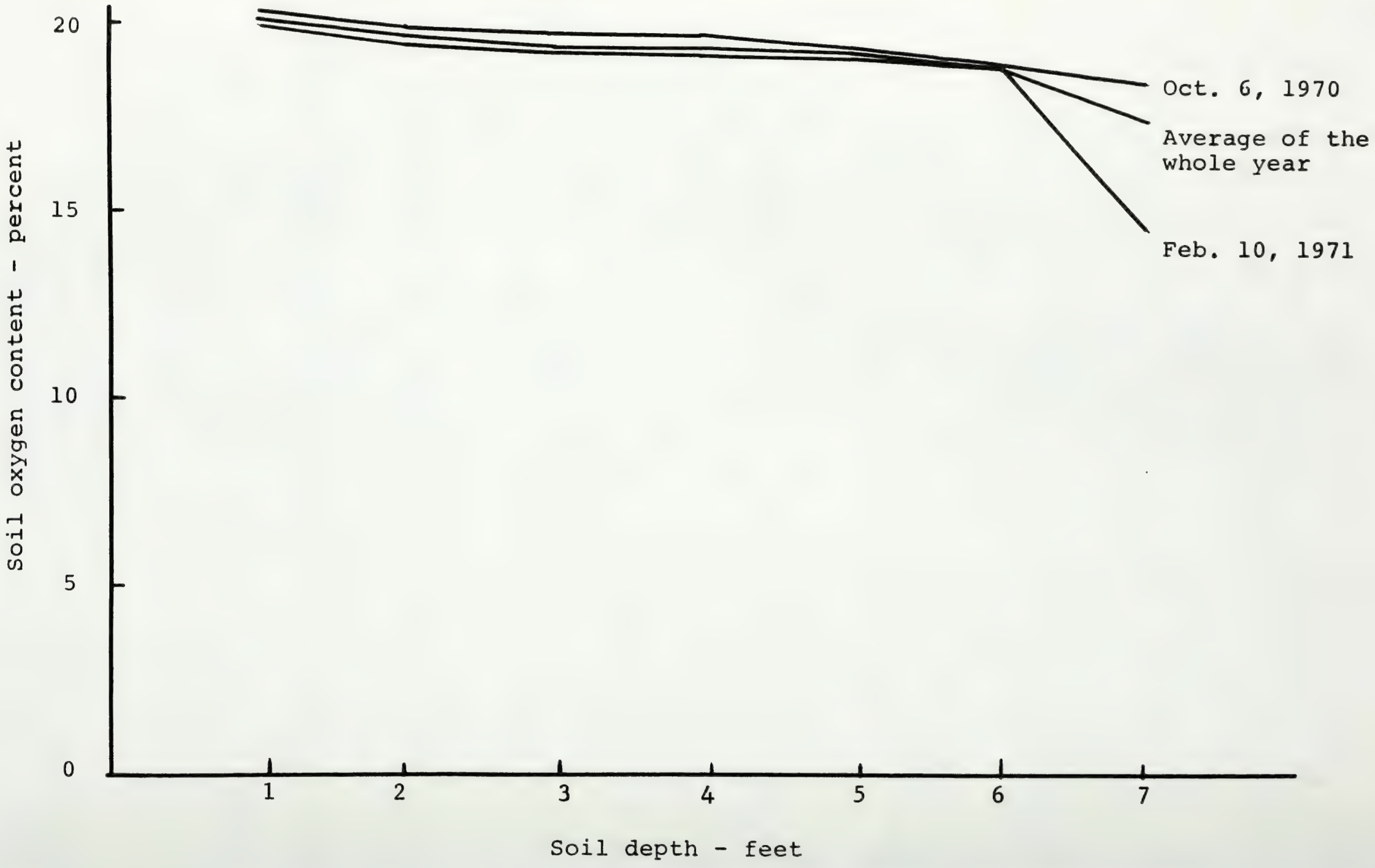

Figure 6.—Changes in soil oxygen content with soil depth in Plot No. 9.

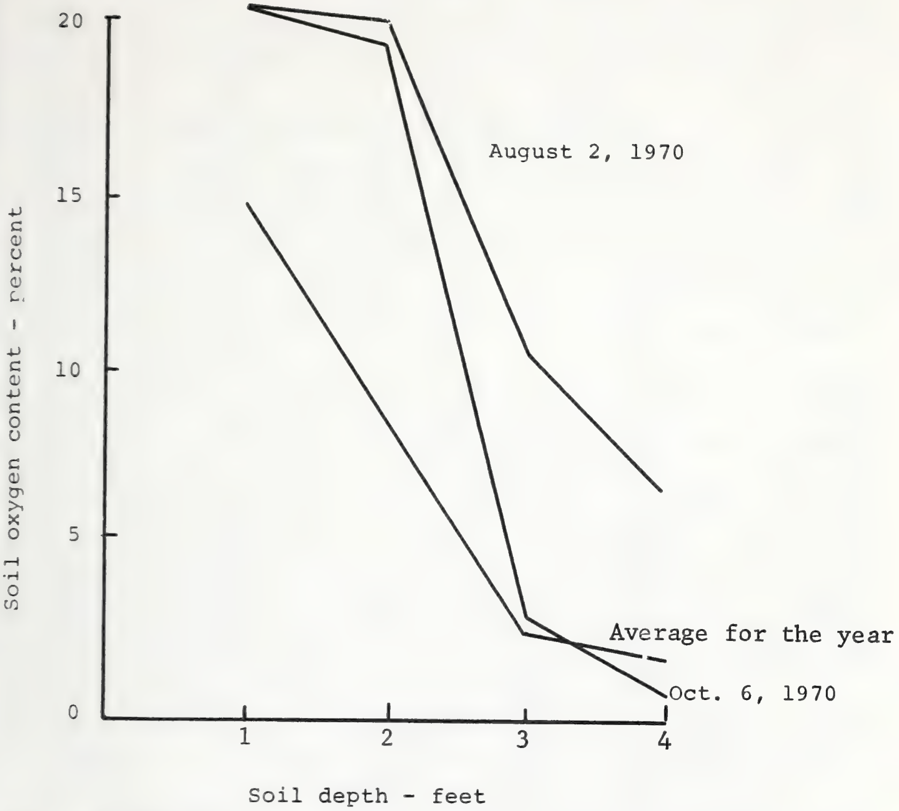

Figure 7.–Changes in soil oxygen content with soil depth in Plot No. 18.

of rainfall received one day or several days before the oxygen readings were taken. The effect of rainfall on soil oxygen content is shown in Figure 8.

The first reduction of soil oxygen occurred on May 5, 1970, as a result of 3.28 inches of rainfall on May 2-3, 1970. On August 31, 1970, marked reductions in the oxygen content at all depths and in all plots were recorded. These sharp decreases in soil oxygen were probably caused by high soil moisture resulting from 4.47 inches of rain which fell between the August 17 and August 31 samplings. Other reductions of soil oxygen content occurred on October 22 and November 18, 1970, and on March 30, 1971. Those reductions of soil oxygen content were also likely due to rains which occurred on October 7-8-9 (5.84 inches), November 13 (1.30 inches), and March 28, 1971 (1.37 inches).

Furr and Aldrich (1943) experienced similar results and reported that marked decreases in soil oxygen contents occurred following rains and

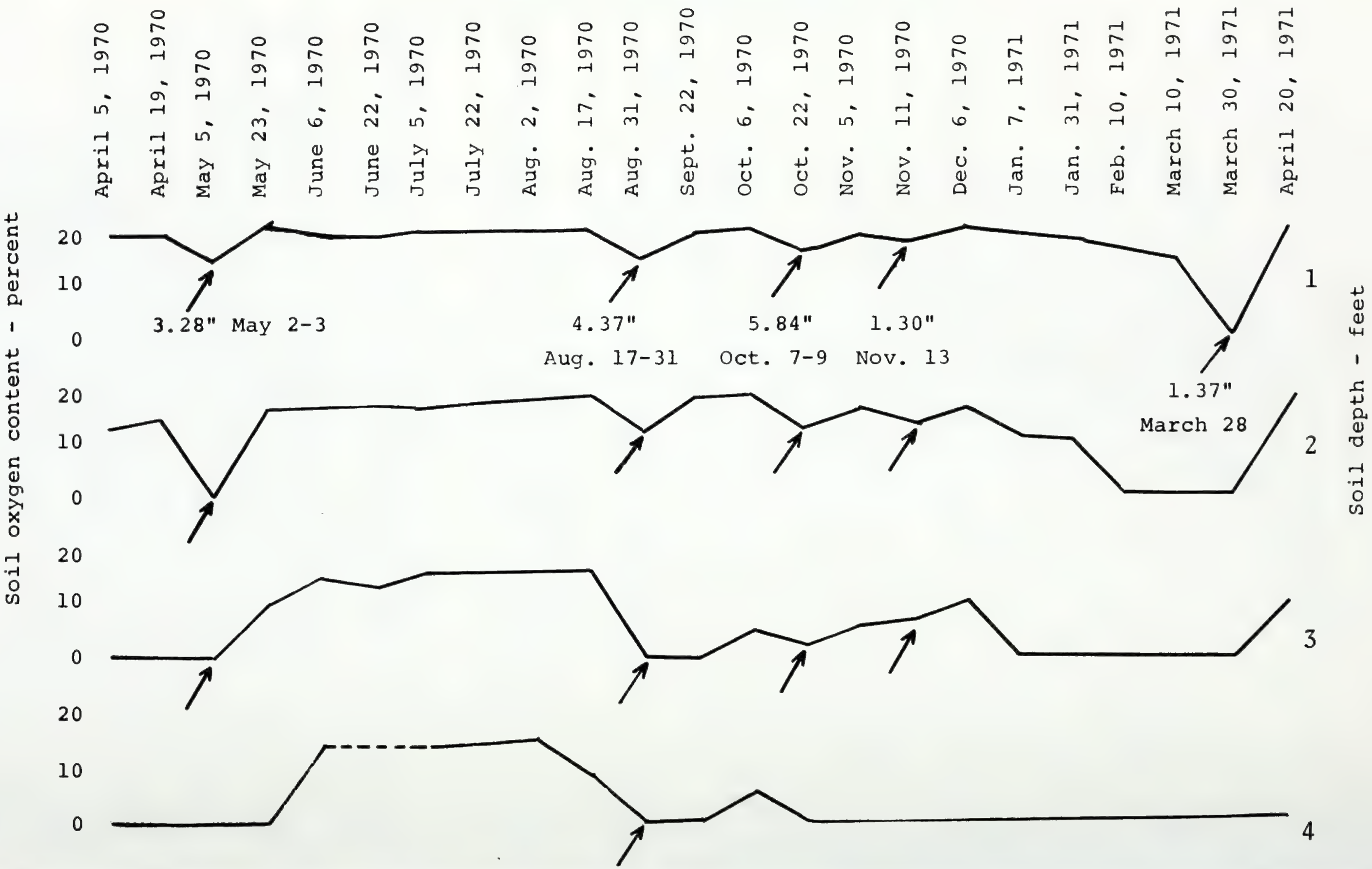

Figure 8.—Effect of rainfall on soil oxygen content in Plot No. 5. Arrows indicate the reduction of oxygen content

irrigation in a very fine sandy loam soil. Patrick and his associates (1969) also noted that the moisture added to the soil by a heavy rain will cause a reduction of oxygen content in the soil.

Relation of Soil Moisture to Oxygen Content

Data on the soil moisture content at each soil depth for all nine plots are presented in the thesis by Hu (1971). However, only six of the nine plots (Plots 1, 5, 7, 9, 10, and 20) were used to test the relationship between soil moisture and soil oxygen by linear correlation analyses. The moisture readings below 3 feet for the three other plots were very high due to the high water table and were therefore excluded from the statistical analyses.

The correlation between soil oxygen content and soil moisture content proved to be negative and highly significant at every soil depth for the plots as a whole. However, the correlation analyses by different depths in individual plots resulted in several nonsignificant correlation coefficients because sample size was small—only 12 observations in each case. But when the data for all six plots were combined in the analysis, the relationship between soil oxygen and soil moisture content was found to be highly significant at every soil depth ranging from $r = -0.5686$ at the 1-foot depth to $r = -0.9350$ at the 7-foot depth. As soil moisture increased the oxygen content decreased; as the soil moisture decreased the oxygen content in the soil increased (Figure 9).

This finding is in general agreement with other reports (Kohnke 1968, Taylor 1949, and others). Taylor reported that oxygen diffusion is strongly influenced by soil moisture. Under natural conditions, an excess of moisture in the soil is one of the situations which may result in poor aeration (Buckman and Brady 1957). Furr and Aldrich (1943) also reported that as the soil moisture content decreased, the oxygen content in the soil increased. Under field conditions, soil moisture is the most profound factor that influences soil oxygen content.

Water Table Influences on Soil Oxygen Content

During the period of study, a high water table was present on six of the nine plots and often prevented the extraction of air samples, especially from the lower depths and during the winter months. In a few plots, notably Nos. 4, 5, 7, 18, and 20, the water receded below the deepest sampling depth only during July and August (see Hu 1971). Water table measurements were not begun until November 5, 1970, after the installation of drainpipes for this purpose. Subsequent measurements on depth to the water table and the corresponding soil oxygen contents in one of these plots are presented in Table 2.

The water table in each of these plots was so high that oxygen-sampling reservoirs at the 3- and 4-foot depths were flooded by free water most of the time so that no soil air could be extracted for oxygen

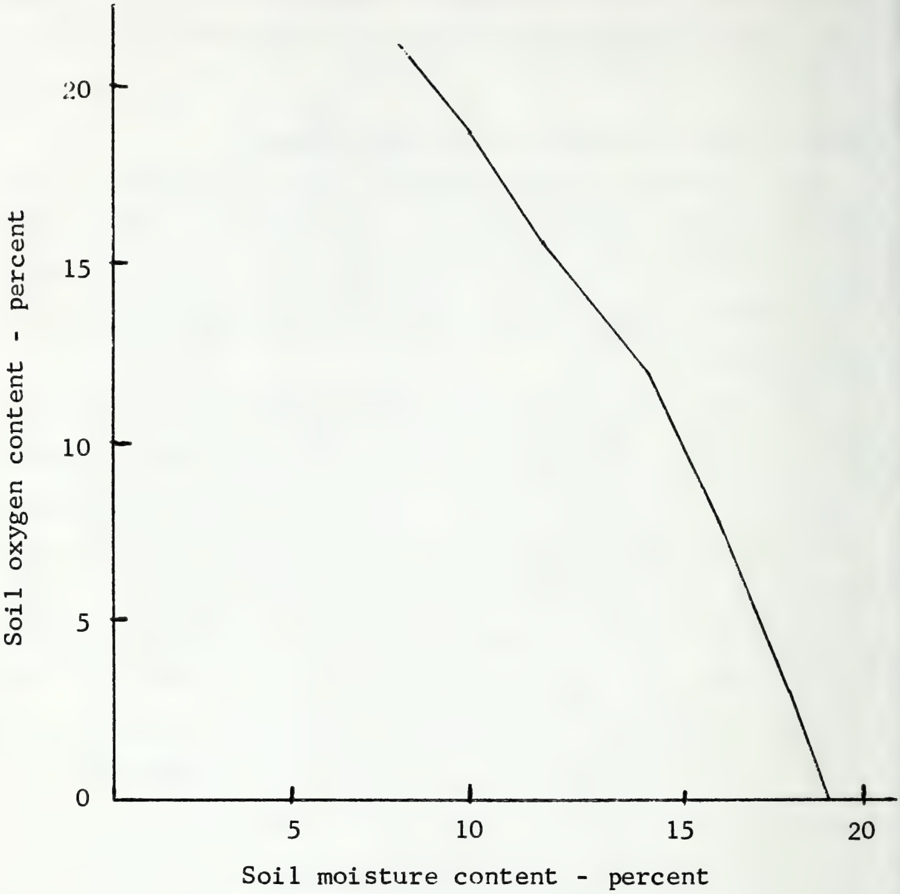

Figure. 9.—The relationship between soil oxygen content and soil moisture content for all plots and depths.

Table 2.—The water table and the corresponding soil oxygen contents in one of the low plots (Plot No. 1) on the LSU Lee Memorial Forest

Date	Depth of water table below the ground surface	Soil oxygen content by depth			
		1 ft.	2 ft.	3 ft.	4 ft.
	Feet	— — — — — — — — Percent — — — — — — — —			
11/ 5/70	3.2	20.0	19.5	7.7	H_2O[a]
11/19/70	3.0	20.0	18.5	H_2O	H_2O
12/ 6/70	4.1	20.5	20.0	8.0	H_2O
1/ 7/71	1.7	18.7	H_2O	H_2O	H_2O
1/31/71	1.0	H_2O	H_2O	H_2O	H_2O
2/10/71	0.3	H_2O	H_2O	H_2O	H_2O
3/10/71	0.2	H_2O	H_2O	H_2O	H_2O
3/30/71	0.1	H_2O	H_2O	H_2O	H_2O
4/20/71	3.1	18.0	15.7	3.1	H_2O

[a] Free water table.

measurements. Only the oxygen content in the soil air above the free water could be measured by the oxygen meter. It is obvious from Table 2 that the oxygen content in the soil profile was definitely influenced by fluctuations in the water table. The oxygen content in the soil just above the water table was quite low, no doubt resulting from a very high soil moisture content in the capillary zone above the surface of the water table.

Young (1969) conducted an experiment on two wetland forest soils and found a similar relationship between soil oxygen and the water table. He reported that as fluctuating water table levels dropped, the oxygen diffusion rates increased in both soils. Patrick and his associates (1969) had difficulty with their oxygen samplings due to the high water table during the first part of the growing season. Generally, soils with low water tables and coarse texture have high air capacities (Kohnke 1968) and in turn can have high contents of oxygen for plant growth.

Effect of Slope on Soil Oxygen Content

One of the study plots—No. 10—is located on a slope of 17 percent. The effect of the slope on oxygen content is shown in Figure 10. The oxygen content in the soil at the top of the slope was generally higher than on the middle-slope position, which in turn was higher in oxygen content than at the bottom of the slope. However, this was true only below the 2-foot depths; at the upper soils depths the oxygen content was rather uniform across the slope positions.

The effect of slope on soil oxygen content in Plot 10 may be explained by soil moisture differences across the slope. The soil moisture at the top of the slope was normally lower than on the middle-slope position, which in turn was lower in soil moisture content than at the bottom of the

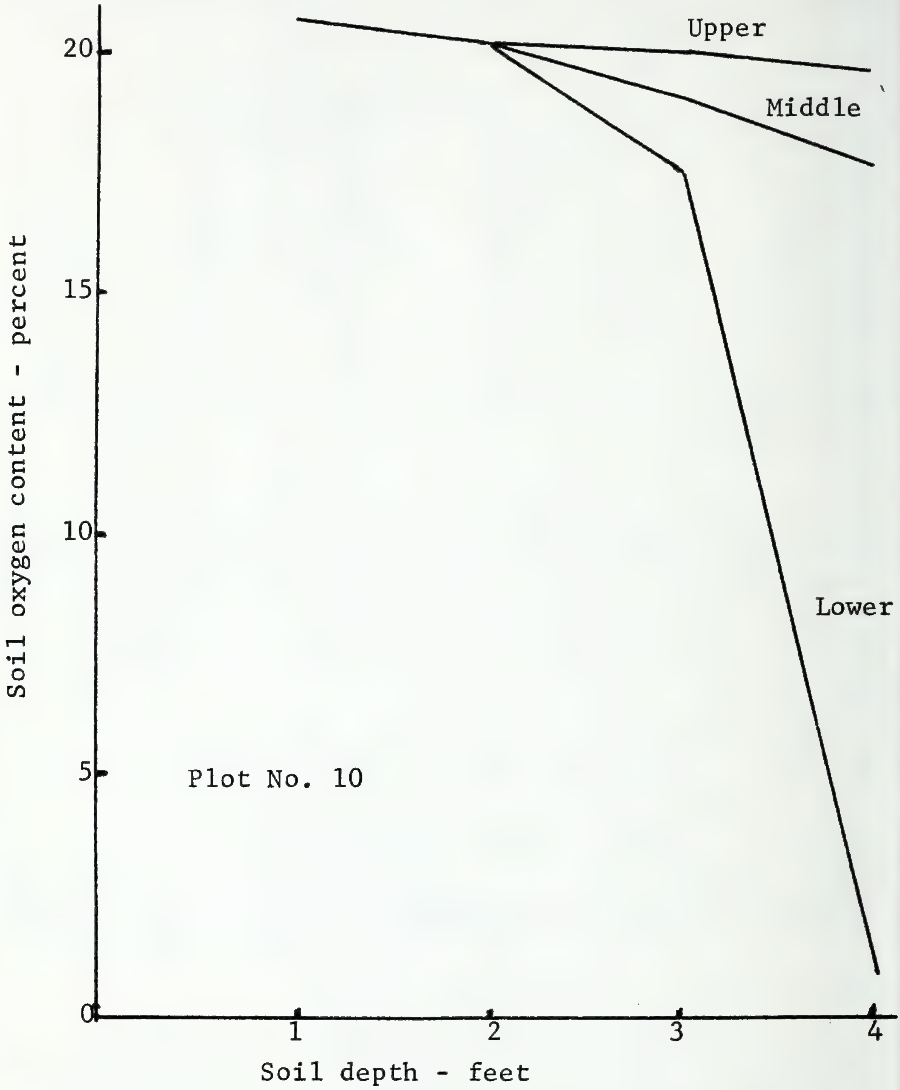

Figure 10.—Soil oxygen content changes with slope.

slope. Through the study period, soil moisture at 4 feet averaged 7.20, 12.56, and 14.95 percent in the upper, middle, and lower slope positions, respectively. Likewise at 6 feet, soil moisture averaged 6.85, 14.58, and 17.14 percent, respectively, from top to bottom of the slope.

Soil Oxygen Content as Related to Other Physical Properties of the Soil

A correlation analysis was used to test the relationship of soil oxygen content to other physical properties of the soil: percent of sand, silt, and clay; capillary, non-capillary, and total porosity; and bulk density. The calculated correlation coefficients were then tested for significance by the F-test. The soil oxygen data used in the correlation analyses were the average soil oxygen contents for the whole year (average of the 23 biweekly readings) at each soil depth.

The relationship between soil oxygen content and non-capillary porosity proved to be highly significant and positive ($r = 0.6056$). The positive coefficient indicates that the oxygen content in the soil profile increased as non-capillary porosity increased. This is in general agreement with other findings (Robinson 1964, Vomocil and Flocker 1961, and Kohnke 1968). A soil is considered well-aerated for crop plants if the non-capillary porosity is 10 percent or more of the total volume, unless there is a high water table (Kohnke 1968). In Plot 9, the non-capillary porosity of the soil profile down to 7 feet exceeds or is very close to 10 percent. The oxygen contents also were not critical at any time during the year in this plot (Figure 2). Likewise, the non-capillary porosity and therefore the oxygen contents in Plot 10 are also adequate for tree growth at all depths, except perhaps at 6 feet where there is only 6.51 percent non-capillary porosity. But in the low sites, such as Plots 1, 4, 5, 18, and 20, the non-capillary porosities at all depths are less than 10 percent. The oxygen contents below 1 foot are not considered adequate for optimum tree growth.

The relationship between capillary porosity and soil oxygen content was also significant. However, their correlation coefficient is negative ($r = -0.4117$), which means that as the capillary porosity increased the oxygen content in the soil profile decreased. Since capillary porosity is responsible for soil moisture retention, this finding is also in general agreement with other early reports. Lemon and Erickson (1952) reported that the diffusion of oxygen is a linear function of water-free porosity.

The relationship between total porosity and soil oxygen content was not statistically significant. Since there are positive and negative relationships between soil oxygen content and non-capillary and capillary porosity, respectively, the effect of total porosity is probably canceled out in this particular case.

No significant relationship was found between soil oxygen content and percentages of sand, silt, and clay. Bulk density also was not significantly related to soil oxygen content. This does not agree with the findings of other workers (Baver 1956, Epstein and Kohnke 1947, Kohnke 1968, Patrick 1971, Rickman et al. 1965 and 1966, and others) who have reported that texture and bulk density do affect the soil oxygen content. Soil texture and bulk density are the prime factors in determining porosity; thus, direct measurement of porosity is probably a better indicator of aeration than either texture or bulk density alone.

Soil Oxygen Content and Loblolly Pine Tree Growth

It was earlier reported (Kramer 1950) that root systems of loblolly pine seedlings were severely damaged under conditions of soil oxygen deficiency without visible symptoms of injury to the tops of the seedlings. There is also evidence that tolerance to oxygen deficiency increases with the age of the tree (Grable 1966, Leyton and Rousseau 1958). Since most of the plots in the present study were characterized by low soil oxygen levels during the winter and early spring, it would seem reasonable to assume that the root systems of loblolly pine trees growing on the study plots might be adversely affected by these low soil oxygen levels as they grow to maturity. Soil oxygen levels were found to be particularly low in sample plots located on wet sites and at lower depths in the subsoils of some of the drier plots.

The site index values for loblolly pine on the nine study plots ranged from 98 to 118 (Table 1). These values indicate that the trees grew well on all of the plots and that, in general, loblolly pine must be rather tolerant to the low soil oxygen contents in the winter and early spring. In fact, the three wet plots (17, 18, and 20) had the highest site index values (115, 113, and 118, respestively). Furthermore, if a soil oxygen content of 10 percent or more throughout the year is considered necessary for normal root activity and rapid growth, then only one of the study plots (Plot 9) did not reach the critical levels of soil oxygen at any measured depth throughout the year. The lowest soil oxygen content recorded on this plot was 14.6 percent at 7 feet on February 10, 1971. The site index on Plot 9 is only 100, a much lower index value than those for Plots 17, 18, and 20, despite the fact that soil oxygen contents on these latter plots were less than 10 percent during much of the year, especially at depths greater than 4 feet.

Most loblolly pine trees have roots which not only extend beyond the spread of the branches but also penetrate deeply into the soil profile. The rooting depth of trees varies from several inches to several feet, depending on soil characteristics such as aeration and drainage (Kramer and Kozlowski 1960). Ninety percent of the small roots were distributed within 5 inches in the topsoils in forests of North Carolina (Coile 1937). The heavy distribution of roots near the surface of the soil is probably related to poorer aeration at the greater depths (Kramer and Kozlowski 1960). The oxygen contents in some of the study plots were usually low in subsoils (below 4 feet) during the growing season, therefore the oxygen-absorbing root systems of these loblolly pine trees may be limited to the upper 4 feet of the soil profile.

Low soil oxygen content during winter and early spring apparently does not seriously limit the growth of loblolly pine even on wet sites. Soil oxygen content reaches adequate levels on these sites after the initiation of growth and active transpiration. A comparison of Plot 9 (site index 100, soil oxygen contents greater than 10 percent at all measured depths throughout the year) and Plots 17, 18, and 20 (site index 115, 113, and 118, respectively, low soil oxygen contents in winter and early spring) suggests that the presence of readily available water early in the growing season may be more important for the growth of loblolly pine trees than is an adequate soil oxygen level at this time. Tree growth on Plot 9, a Ruston sandy loam soil located on a hilltop, may be limited by insufficient soil moisture in the early spring despite adequate soil oxygen at this time.

Obviously, both sufficient soil moisture and adequate soil oxygen are necessary for good growth of loblolly pine trees. Optimum growth probably depends upon a proper balance of both factors throughout the growing season.

Results of this study suggest that low soil oxygen content in winter and early spring is not detrimental to the growth of loblolly pine trees if levels of soil oxygen content at depths to 4 feet rise to more than 6 percent later in the growing season. Further, comparisons of site index values between the various sample plots indicate that under the above conditions a high level of soil moisture during part of the growing season, even at the expense of adequate soil oxygen, may be more beneficial to rapid growth of loblolly pine trees than the opposite condition, i.e. soil oxygen content greater than 10 percent but soil moisture limited.

Summary

Soil oxygen content is very essential to normal root activity and growth of trees. Deficiency of soil oxygen affects root growth, water uptake by roots, nutrient absorption and availability, root morphology, disease incidence, and auxin metabolism of various plants. In order to have optimum root growth and development, trees must have adequate soil oxygen. But the requirement of soil oxygen for optimum growth varies with species and age of the plants. Most plants require at least 10 percent of soil oxygen for good growth.

The main purposes of this study were to measure the soil oxygen content under mature loblolly pine trees and to find out how it changes with season and with depth. An attempt was also made to relate the soil oxygen content to such soil factors as moisture content, texture, porosity, bulk density, and depth to the water table.

Nine circular quarter-acre plots were selected for this study at different locations and on different soil types on the University's Lee Memorial Forest near Franklinton, Louisiana. The plots were located in even-aged loblolly pine stands. Hardwood trees and brush in all plots were eliminated by cutting or injection and periodic spray applications of herbicide. Samples of soil air were drawn from air reservoirs established at various depths in each plot with three replicated installations per plot. The measurements were made with an oxygen meter and cell at 2-week intervals at each soil depth. The oxygen measurements were started on April 4, 1970, and were continued for a year to determine the seasonal pattern of soil oxygen changes under these mature loblolly pine stands.

Weekly soil moisture measurements were made with a neutron soil moisture probe in access tubes previously installed in the center of each plot. In plots where a free water table was present, a drainpipe was installed and depth to the water table was measured biweekly.

Soil samples were collected from each soil depth in each plot for determination in the laboratory of bulk density, texture, and porosity. The relationship of these soil physical properties to soil oxygen content was then determined by correlation analysis.

An analysis of variance was used to determine the effects of seasonal changes and soil depth on oxygen content in the soil profile. The influence of soil moisture on soil oxygen content was determined by a correlation analysis and the significance of the correlation coefficients determined by the F-test.

The results of the study are as follows:

1. The oxygen content in the forest soils under these mature loblolly pine stands varied throughout the year. Usually it was lower in winter and early spring and increased as the growing season progressed, especially in subsoils and on low sites.

2. The oxygen content also changed with soil depth throughout the whole year. In general, the oxygen content in the soil profile decreased with depth. Seasonally, the greatest decrease of soil oxygen content with depth occurred during the winter and early spring. This reduction of soil oxygen content with depth was also greater in wet sites than in drier sites.

3. The oxygen content in the forest soils was definitely influenced by soil moisture content. As the soil moisture content increased, the oxygen content in the soil profile decreased. A higher moisture content in the soil profile caused by a heavy rain also reduced the oxygen content in the soil.

4. The oxygen content in these forest soils under mature loblolly pine stands was greatly influenced by the fluctuating water table. As the water table became higher, the oxygen content in the soil strata immediately above the water table was sharply reduced.

5. There seemed to be a relationship also between soil oxygen and slope. The oxygen content at the top of the slope was normally higher than at the middle of the slope, which in turn was higher than at the bottom of the slope at the same soil depth. This may be related to differences in soil moisture content across the slope.

6. A significant relationship was found between soil oxygen content and capillary and non-capillary porosity. As expected, the correlation coefficient for capillary porosity was negative and for non-capillary porosity positive. As the capillary porosity increased, the oxygen content in the soil profile decreased; as the non-capillary porosity increased, the oxygen content in the soil increased.

7. No significant relationship was established between soil oxygen content and either soil texture or bulk density in this study.

8. Mature loblolly pine trees are probably rather tolerant to low soil oxygen content. Low soil oxygen content in the winter and early spring or in subsoils (below 4 feet) apparently was not detrimental to the growth of these trees. Optimum growth of loblolly pine trees perhaps depends more on the proper balance of soil oxygen and soil moisture content throughout the growing season rather than on a minimum level of oxygen alone.

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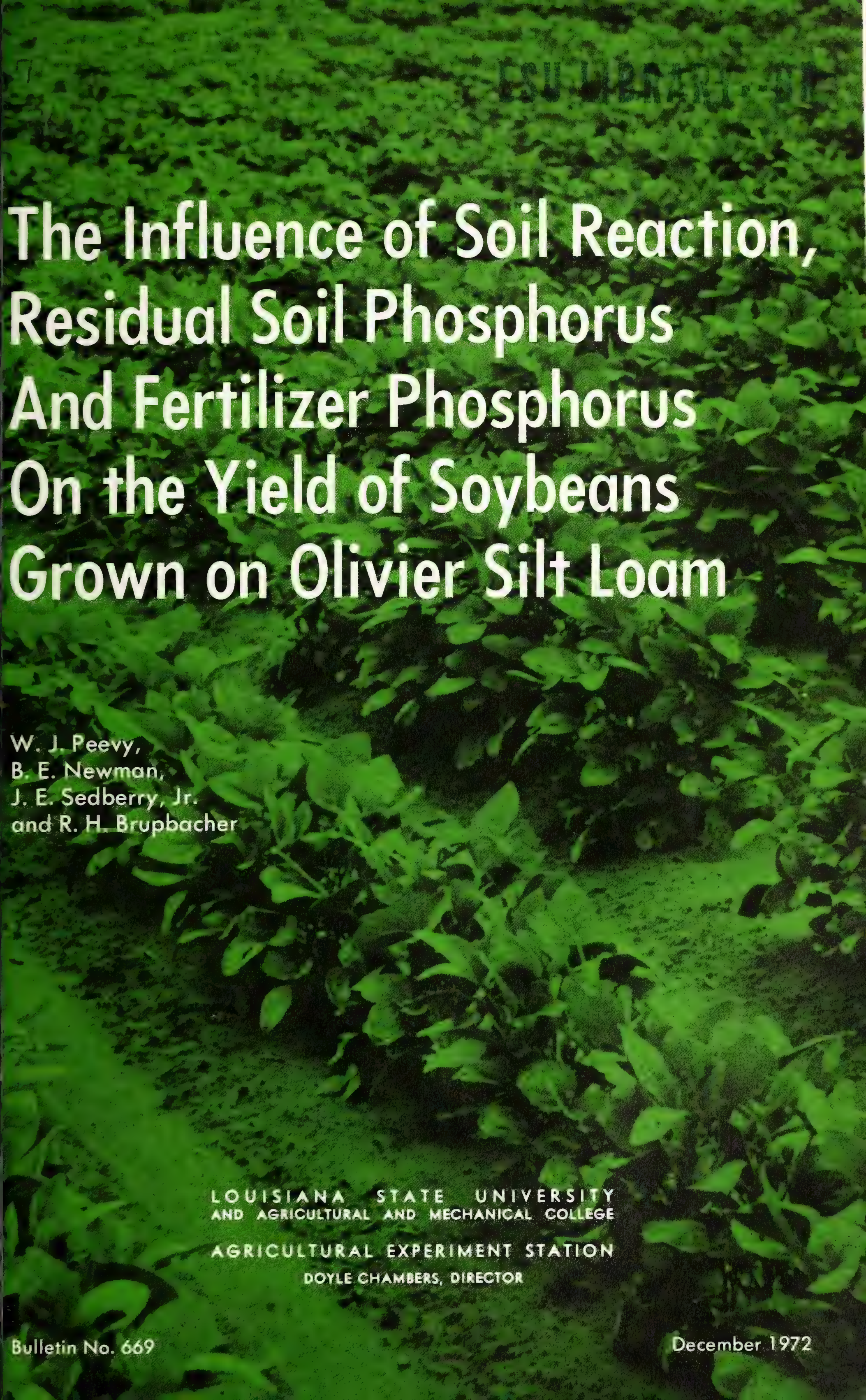

The Influence of Soil Reaction, Residual Soil Phosphorus And Fertilizer Phosphorus On the Yield of Soybeans Grown on Olivier Silt Loam

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The Influence of Soil Reaction, Residual Soil Phosphorus and Fertilizer Phosphorus on The Yield of Soybeans Grown on Olivier Silt Loam

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Introduction

An experiment was initiated in 1967 to determine the effects of soil reaction (pH), residual soil phosphorus and fertilizer phosphorus on the yield of soybeans grown on Olivier silt loam soil at Perkins Road Farm, Baton Rouge. The Olivier soil occurs in the Loessial Hills and Mississippi Terrace areas of Louisiana, which are shown in Figure 1.

The experimental area, approximately 3 acres, had been in a cotton-corn rotation for 18 years. The two chief variables in this rotation that had appreciable effects on soil composition were limestone and phosphorus applications. As a result of phosphorus additions for 18 years prior to 1967, the extractable soil phosphorus ranged from 13 to 60 ppm. The pH was about 5.0 on one-half of the area and about 5.5 on the other half. Because of this relatively wide range in extractable soil phosphorus, and the ability to make rapid changes in soil reaction by limestone additions, this area was considered suitable for a study of the effects of soil reaction, residual phosphorus and applications of fertilizer phosphorus on the yield of soybeans.

The analyses of many thousands of soil samples from the Loessial Hills and Mississippi Terraces have shown that most of these soils are relatively low in extractable phosphorus, and are acid (*1, 3, 4*).[2] Many studies have shown that residual phosphorus from fertilizer applications supplies phosphorus to plants. The oldest work of this nature has been done at the Rothamsted Experiment Station in England, as reported by Russell, (*5*). He reported that after 60 years of cropping, barley plants were still taking up 1.2% of the residual phosphorus in the soil, or about 4.4 pounds of P per acre annually.

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[2] Italic numbers in parentheses refer to Literature Cited, page 20.

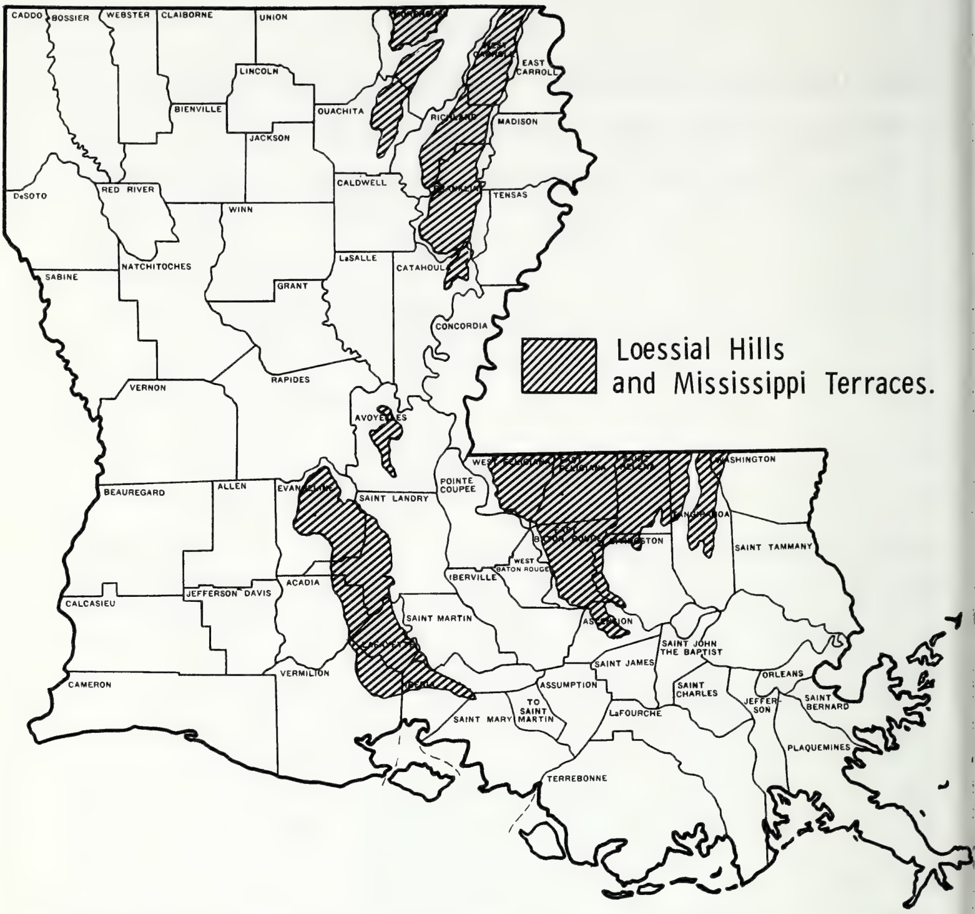

Figure 1.—Location of Loessial Hills and Mississippi Terraces in Louisiana.

More recently, Ensminger (*2*) reported on work in Alabama which showed large increases in cotton yields from residual phosphorus 20 years after any fertilizer phosphorus had been applied. Although there was a large benefit from residual phosphorus, the level was not sufficient to prevent a further yield increase from the use of more fertilizer phosphorus.

The Olivier silt loam soil on which this investigation was conducted occurs in, and is quite representative of, an area that is quite different from other soil areas in Louisiana. The results of this investigation should help farmers in this soil area (Figure 1) to determine their phosphate fertilizer and lime needs.

Experimental Procedure

The experimental area was divided into four blocks. One block was then limed to pH 6.4 and one was limed to pH 7.0. Two blocks, which had a pH of about 5.1 and 5.6, respectively, were left unlimed. Each block then consisted of 18 plots, which had variable extractable soil phosphorus levels because of previous P applications for 20 years. These plots were then subdivided and phosphorus was applied to one-half of each plot at the rate of 60 pounds of P_2O_5 (26 pounds P) per acre annually in 1967, 1968 and 1969. The phosphorus was applied and bedded-on before planting. Ordinary 20% superphosphate was used as the source of phosphorus. Potassium was applied as potassium chloride to all plots at the rate of 100 pounds of K_2O (83 pounds K) in 1967, and at the rate of 60 pounds of K_2O (50 pounds K) per acre in 1968 and 1969. Bienville soybeans were grown annually.

Results and Discussion

All data presented are average yields for the 3 years of this experiment—1967, 1968 and 1969. During 1969 the weather was very dry and yields were very low. The average yield for all plots at pH 7.0 for 1967 and 1968 was about 40 bushels per acre. The average yield in 1969 was 25 bushels. The 3-year average was about 35 bushels.

Soybean Production at pH 5.1

The 3-year average yields of soybeans at pH 5.1 for each plot, both with and without fertilizer phosphorus, are shown in Table 1. Although the use of phosphorus on plots with very low soil phosphorus gave good yield increases, the total yields were still very low. On plots with the higher phosphorus levels, the total yields were also very low and there was less response to the use of phosphorus.

The yields at five specific soil phosphorus levels at pH 5.1 are shown graphically in Figure 2. This shows that there was a moderate response to phosphorus at very low soil phosphorus levels, very little response as the soil phosphorus increased to above 30 ppm, and that all yields were low.

The yield differences shown in Table 1 are shown graphically in Figure 3. A highly significant negative linear regression equation was obtained, indicating that as the soil phosphorus approaches 25 to 35 ppm there is little chance of a response to the use of phosphorus fertilizer at soil pH 5.1.

Table 1.—Effects of soil phosphorus and fertilizer phosphorus on the yield of Bienville soybeans grown on Olivier silt loam soil at pH 5.1

Extractable P in soil	P added	No P added	Yield difference
ppm	— — — — — Yield, bushels per acre — — — — —		
15	16.1	9.1	+7.0
15	17.1	12.9	+4.2
15	21.5	15.7	+5.8
18	24.1	14.3	+9.8
18	21.0	13.1	+7.9
18	15.9	10.3	+5.6
20	14.0	12.5	+1.5
23	15.1	13.6	+1.5
25	16.7	19.0	—2.3
28	18.9	20.9	—2.0
28	18.8	17.1	+1.7
28	20.9	19.7	+1.2
30	20.2	16.4	+3.8
30	22.3	18.2	+4.1
33	21.9	18.8	+3.1
35	20.2	19.9	+0.3
35	24.4	21.9	+2.5
Average:	19.6	16.5	

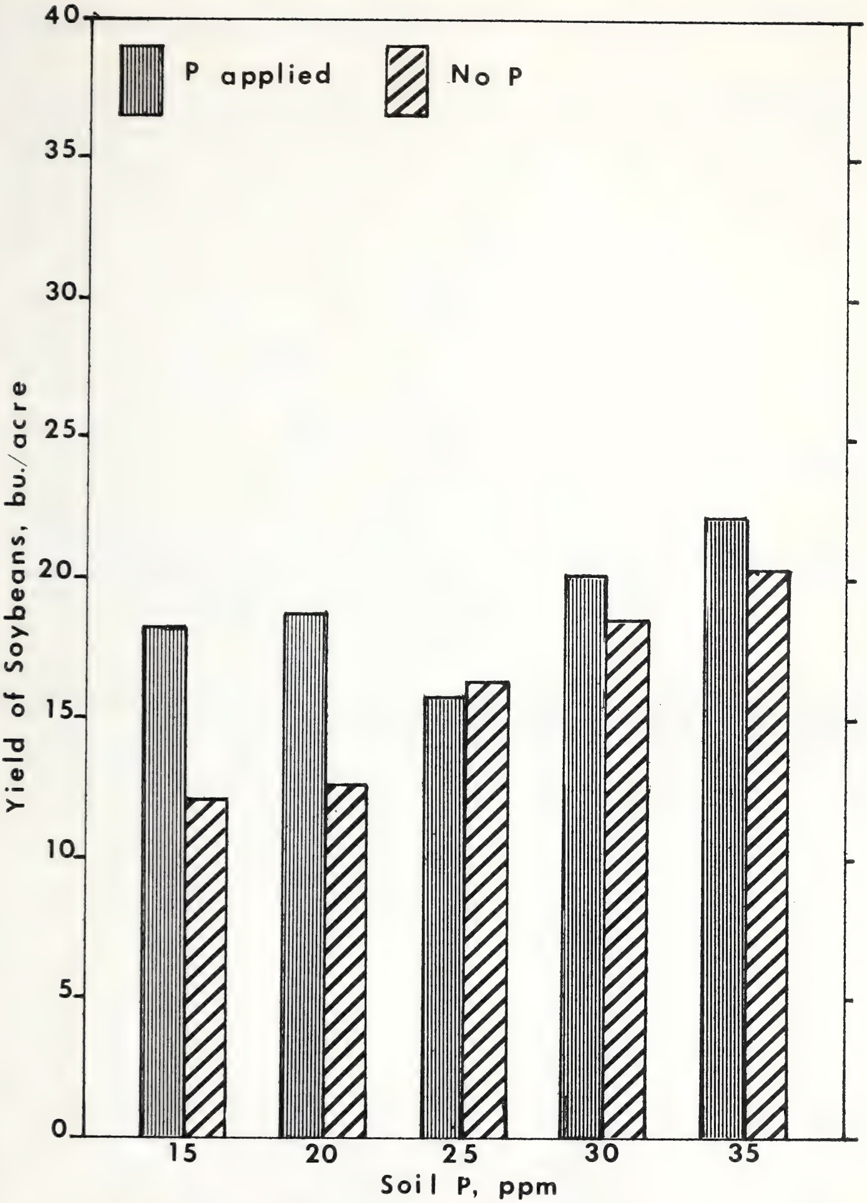

Figure 2.—Effects of levels of soil P and applied P on the yield of Bienville soybeans grown on Olivier silt loam, pH 5.1.

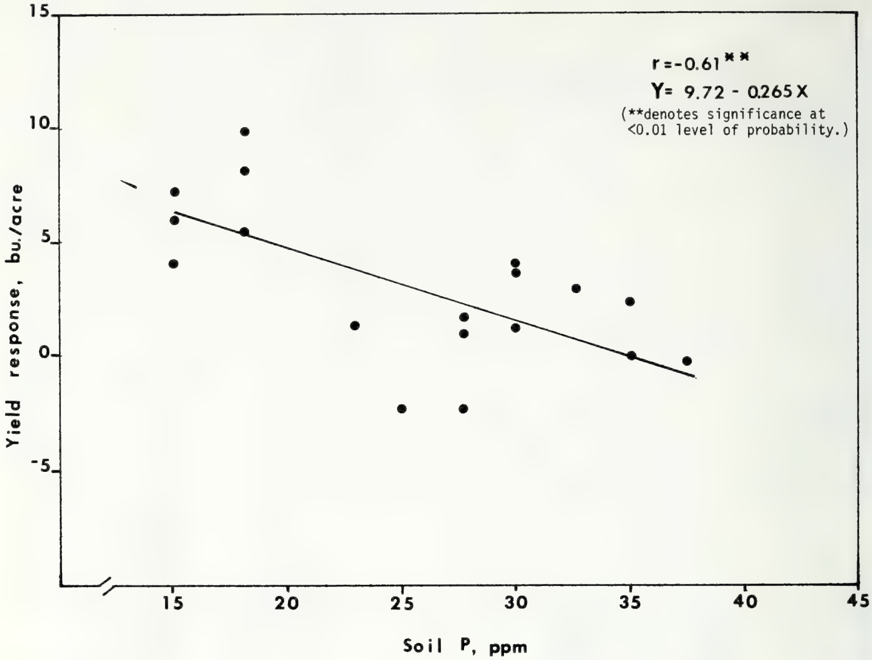

Figure 3.—Effects of levels of soil P on the response of Bienville soybeans to applied P on Olivier silt loam, pH 5.1.

Soybean Production at pH 5.6

The 3-year average yields of soybeans at pH 5.6 for each plot are shown in Table 2. The yields without fertilizer phosphorus and the responses to fertilizer phosphorus were considerably larger at pH 5.6 than at pH 5.1. Even with the use of fertilizer phosphorus, the yields were mostly under 30 bushels per acre at all soil phosphorus levels, indicating that this pH was too low for high soybean yields on this soil.

The average yields at five selected soil phosphorus levels are shown graphically in Figure 4. This graph shows that the response to phosphorus generally decreased as the soil phosphorus level increased. The average yields at all soil phosphorus levels were considerably higher than at pH 5.1. Yields without fertilizer phosphorus were higher at pH 5.6 than with fertilizer phosphorus at pH 5.1.

The responses to phosphorus presented in Table 2 are shown graphically in Figure 5. At pH 5.6, there were fairly large variations in yield response at the various soil phosphorus levels. The straight line negative regression shown in Figure 5 was not statistically significant at the 5% probability level; however, the negative linear regression equation could be considered significant at the 7% level.

Table 2.—Effects of soil phosphorus and fertilizer phosphorus on the yield of Bienville soybeans grown on Olivier silt loam soil at pH 5.6

Extractable P in soil	P added	No P added	Yield difference
ppm	— — — — — Yield, bushels per acre	— — — — —	
20	30.2	18.0	+12.2
20	24.1	14.3	+ 9.8
20	25.9	16.7	+ 9.2
23	28.1	13.9	+14.2
23	22.3	16.2	+ 6.1
23	23.4	20.3	+ 3.1
25	29.8	18.5	+11.3
30	24.0	23.1	+ 0.9
30	30.3	19.8	+10.5
30	26.1	22.5	+ 3.6
30	24.9	25.1	— 0.2
30	26.6	28.3	— 1.7
35	24.5	22.4	+ 2.1
35	31.5	22.4	+ 9.1
35	27.6	20.0	+ 7.6
38	30.1	23.4	+ 6.7
38	26.4	27.4	+ 1.0
45	30.5	25.4	+ 5.1
Average:	28.0	21.0	

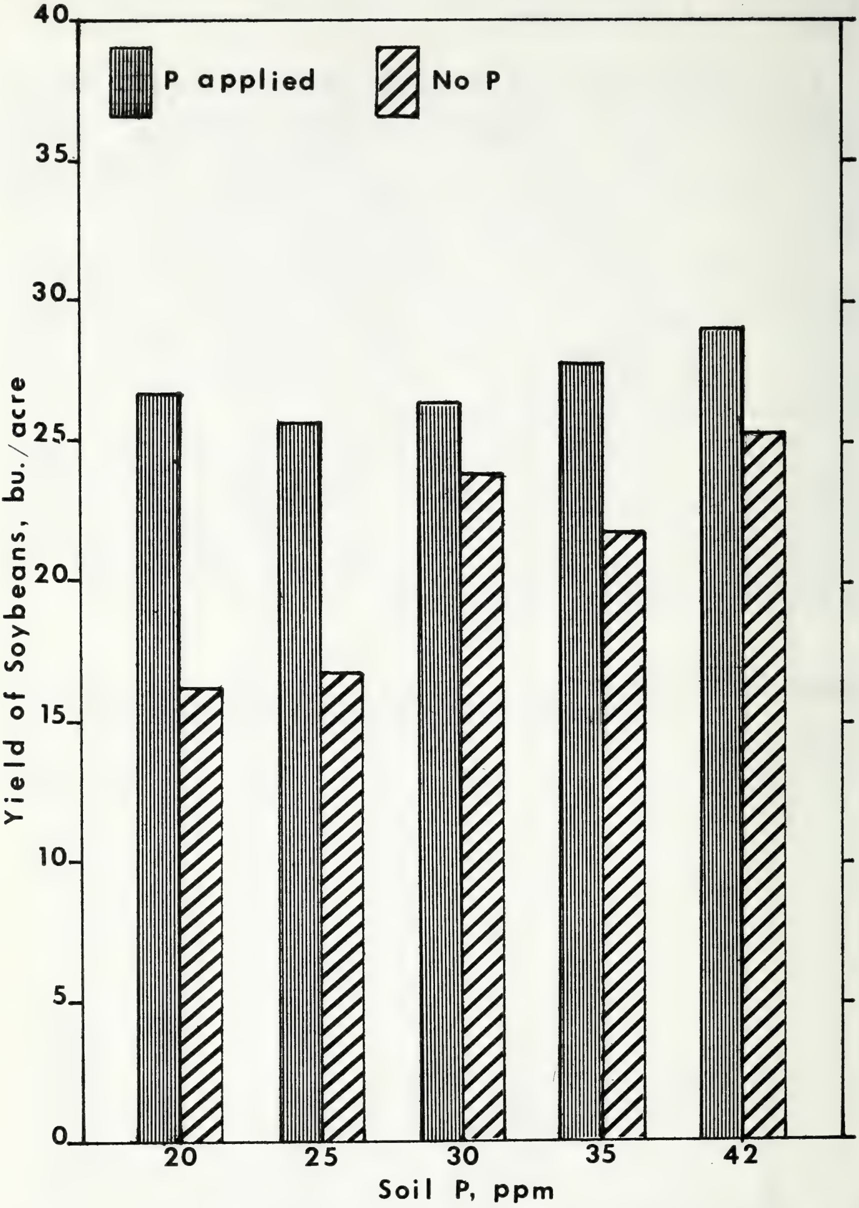

Figure 4.—Effects of levels of soil P and applied P on the yield of Bienville soybeans grown on Olivier silt loam, pH 5.6.

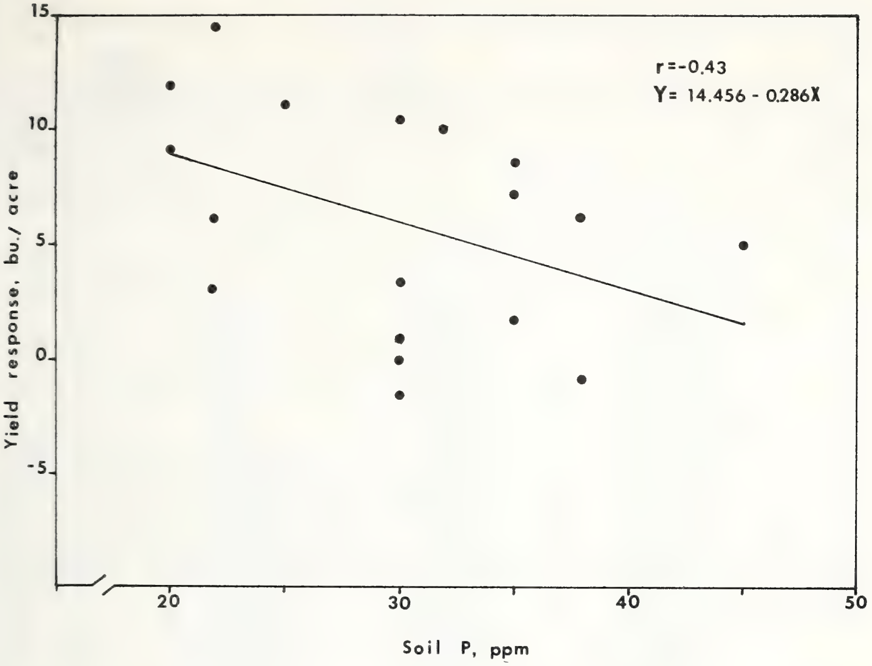

Figure 5.—Effects of levels of soil P on the response of Bienville soybeans to applied P on Olivier silt loam, pH 5.6.

Soybean Production at pH 6.4

The 3-year average yields of soybeans at soil pH 6.4 are shown in Table 3. These yields at pH 6.4 without fertilizer phosphorus were about the same as at pH 5.6 with phosphorus. There was also considerably less response to fertilizer phosphorus at pH 6.4 than at 5.6, but the yields were higher at pH 6.4. This indicated that the lime was causing some absorbed soil phosphorus to become available at pH 6.4.

The average yields at selected soil phosphorus levels are shown graphically in Figure 6. This shows that, at a very low soil-test level of P, there was about a 5-bushel increase from the use of phosphorus, and little increase at a medium (30 ppm) soil phosphorus level. It also shows that the average yield with applied phosphorus at all soil phosphorus levels was above 30 bushels at pH 6.4.

The yield increases as shown in Table 3 are shown graphically in Figure 7. A highly significant negative linear regression is noted. This means that at pH 6.4 on this soil there is likely to be an increase of 5 to 7 bushels per acre at about 15 ppm of soil phosphorus, and that a response to phosphorus is unlikely at a soil-test level of about 30 ppm of phosphorus.

Table 3.—Effects of soil phosphorus and fertilizer phosphorus on the yield of Bienville soybeans grown on Olivier silt loam soil at pH 6.4

Extractable P in soil	P added	No P added	Yield difference
ppm	— — — — — Yield, bushels per acre — — — — —		
13	29.8	24.8	+ 5.0
13	25.5	23.6	+ 1.9
13	31.6	25.3	+ 6.3
15	31.1	28.2	+ 2.9
15	32.2	24.7	+ 7.5
15	31.3	23.9	+ 7.4
20	27.9	23.6	+ 4.3
23	30.7	33.2	− 2.5
23	25.3	26.8	− 1.5
25	32.0	31.1	+ 0.9
25	33.0	31.2	+ 1.8
25	36.6	31.5	+ 5.1
25	30.6	31.8	− 1.2
25	29.2	27.4	+ 1.8
25	26.0	26.6	− 0.6
28	34.6	33.2	+ 1.4
30	32.8	33.1	− 0.3
33	32.7	31.1	+ 1.6
Average:	30.7	28.4	

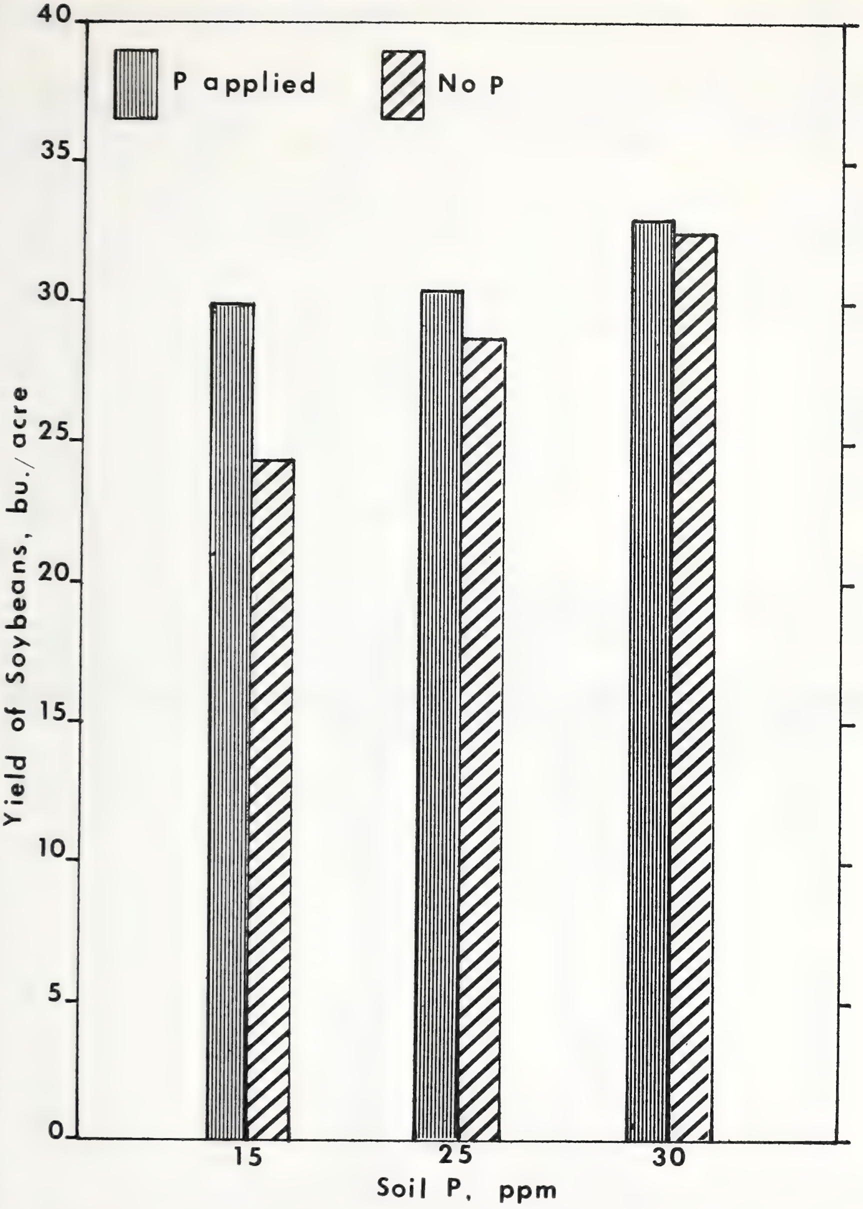

Figure 6.—Effects of levels of soil P and applied P on the yield of Bienville soybeans grown on Olivier silt loam, pH 6.4.

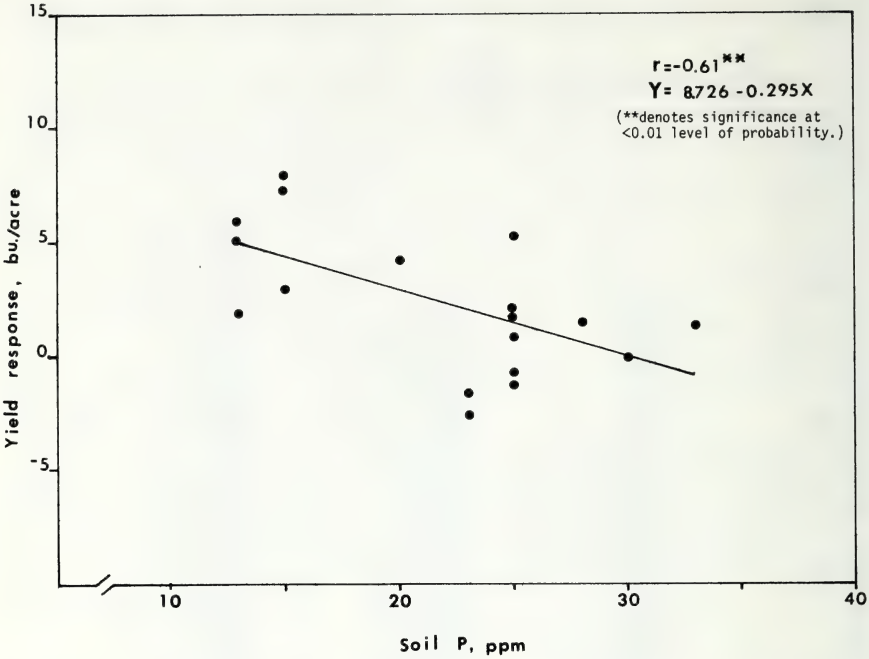

Figure 7.—Effects of levels of soil P on the response of Bienville soybeans to applied P on Olivier silt loam, pH 6.4.

Soybean Production at pH 7.0

The 3-year average yields at pH 7.0 are shown in Table 4. All yields with added phosphorus were 30 or more bushels per acre, regardless of soil phosphorus levels. Also, all except two plots without phosphorus had yields above 30 bushels.

The 3-year average yields at four soil-test phosphorus levels are shown graphically in Figure 8. There was little response to applied phosphorus; however, most important is the fact that at pH 7.0 all yields were relatively high with or without fertilizer phosphorous at all soil phosphorus levels. A comparison of Figures 2 and 8 shows the effect of soil pH on soybean yields on this soil.

The yield differences shown in Table 4 are presented graphically in Figure 9. The linear regression is not statistically significant. It is almost a flat line, which means it is unlikely that much response will be obtained from the use of phosphorus on this soil at pH 7.0, if the soil contains as much as 20 ppm phosphorus.

Table 4.—Effects of soil phosphorus and fertilizer phosphorus on the yield of Bienville soybeans grown on Olivier silt loam at pH 7.0

Extractable P in soil	P added	No P added	Yield difference
ppm	– – – – – Yield,	bushels per acre	– – – – –
20	33.2	34.4	— 1.2
23	32.2	35.0	— 2.8
23	35.8	31.3	+ 4.5
23	34.2	32.7	+ 1.5
25	32.7	32.9	— 0.2
25	36.8	33.3	+ 3.5
28	34.3	33.7	+ 0.6
30	30.0	28.8	+ 1.2
30	35.9	36.6	— 0.7
33	34.1	29.6	+ 4.5
35	35.6	31.7	+ 3.9
40	36.9	34.3	+ 2.6
43	40.2	35.3	+ 4.9
43	35.2	37.4	— 2.2
43	36.6	35.9	+ 0.7
48	40.7	35.9	+ 4.8
48	36.4	35.5	+ 0.9
60	34.0	39.3	— 5.3
Average:	35.3	34.1	

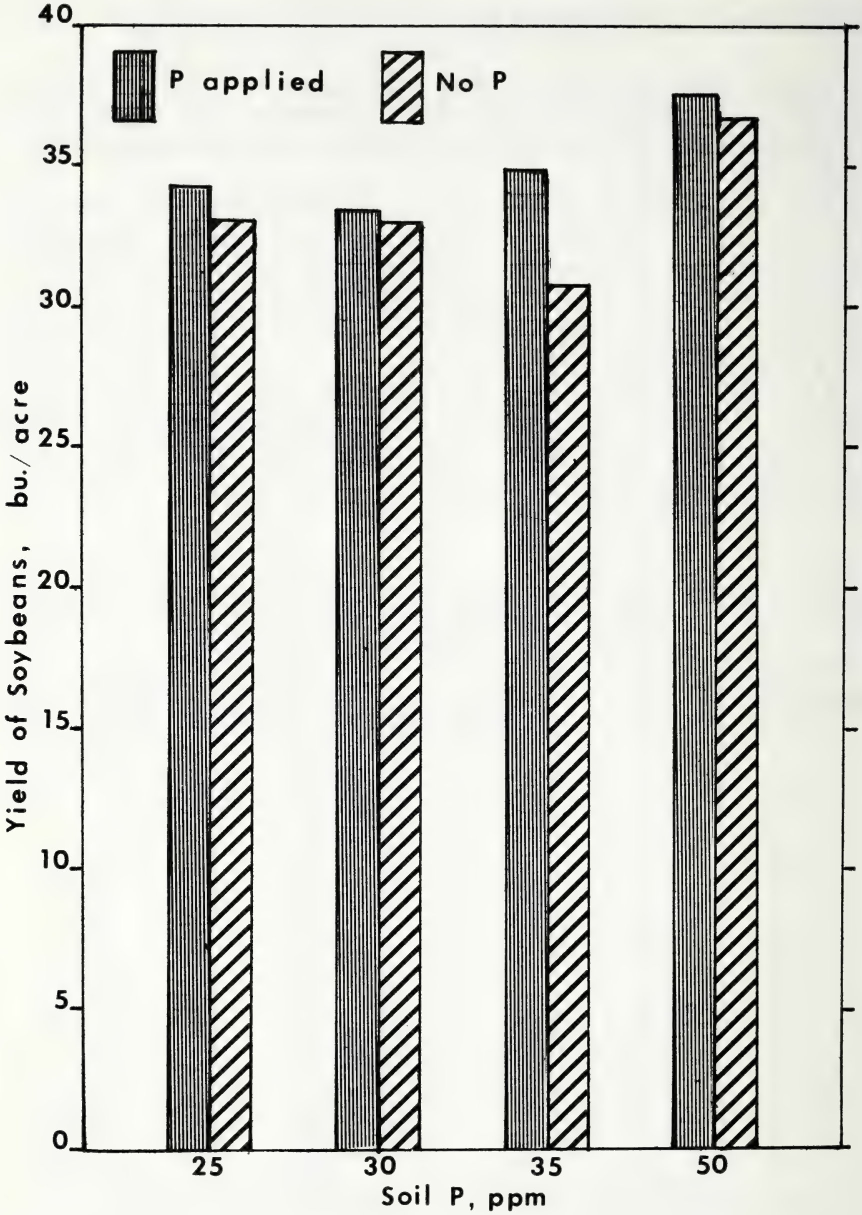

Figure 8.—Effects of levels of soil P and applied P on the yield of Bienville soybeans grown on Olivier silt loam, pH 7.0.

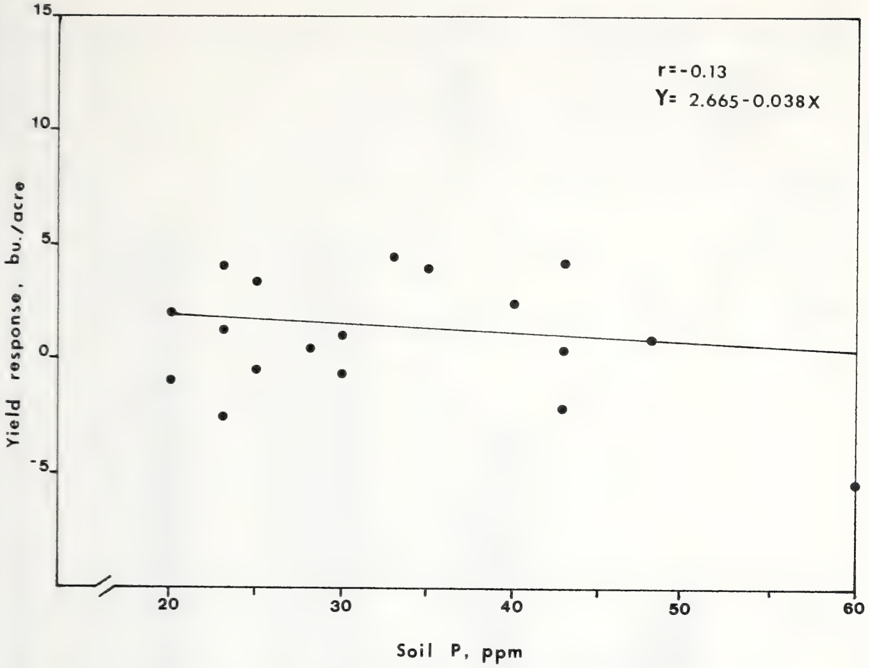

Figure 9.—Effects of levels of soil P on the response of Bienville soybeans to applied P on Olivier silt loam, pH 7.0.

Comparison of pH Effects

To further show the effects of soil reaction on soybean yields on Olivier silt loam, the 3-year average yields at the 30 ppm soil phosphorus level are shown in Figure 10. As shown previously in Figures 2, 4, 6 and 8, there was not much response to phosphorus at a 30 ppm soil phosphorus level at any soil pH. The effects as presented in this graph are from pH alone. With 30 ppm or more of soil phosphorus, the use of fertilizer P did not usually give much increase in yield at any soil pH. However, there was an increase of about 15 bushels per acre at pH 6.5 to 7.0 over pH 5.1.

A further emphasis of the effects of pH is shown in Figure 11. When the 18 plot yields were averaged, as shown in Tables 1 through 4, the "average" effect of lime without fertilizer phosphorus was a straight line graph from pH 5.1 to pH 7.0. With phosphorus, there was a small response at pH 5.1, a good response at pH 5.6, and relatively little average response at pH 6.4 and pH 7.0. This shows the need for a high pH on these soils, with or without the use of phosphorus. At a very low soil pH, phosphorus is of very limited value and yields are low. At a high pH, phosphorus is of limited value above 20 ppm, and yields are high.

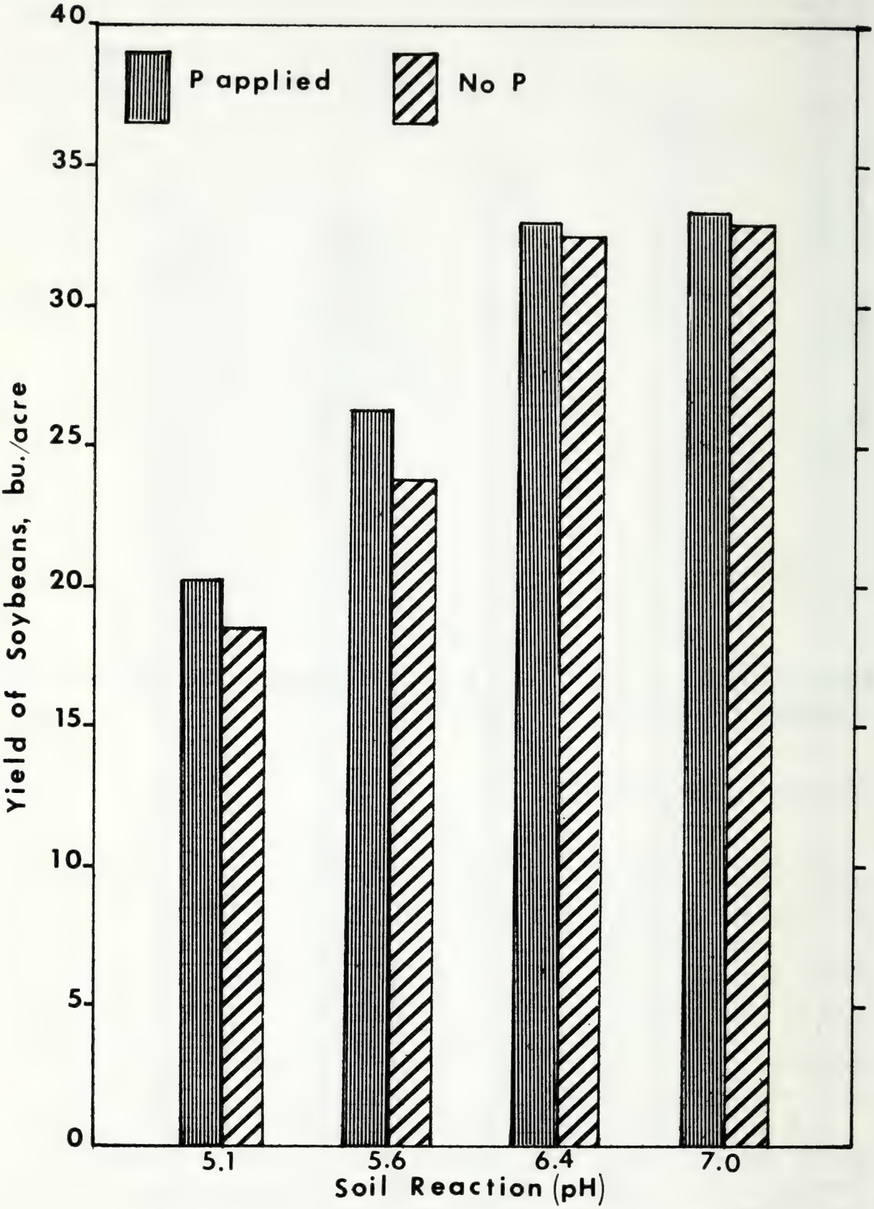

Figure 10.—Influence of soil reaction (pH) and applied P on yields of Bienville soybeans grown on Olivier silt loam with 30 ppm of soil phosphorus.

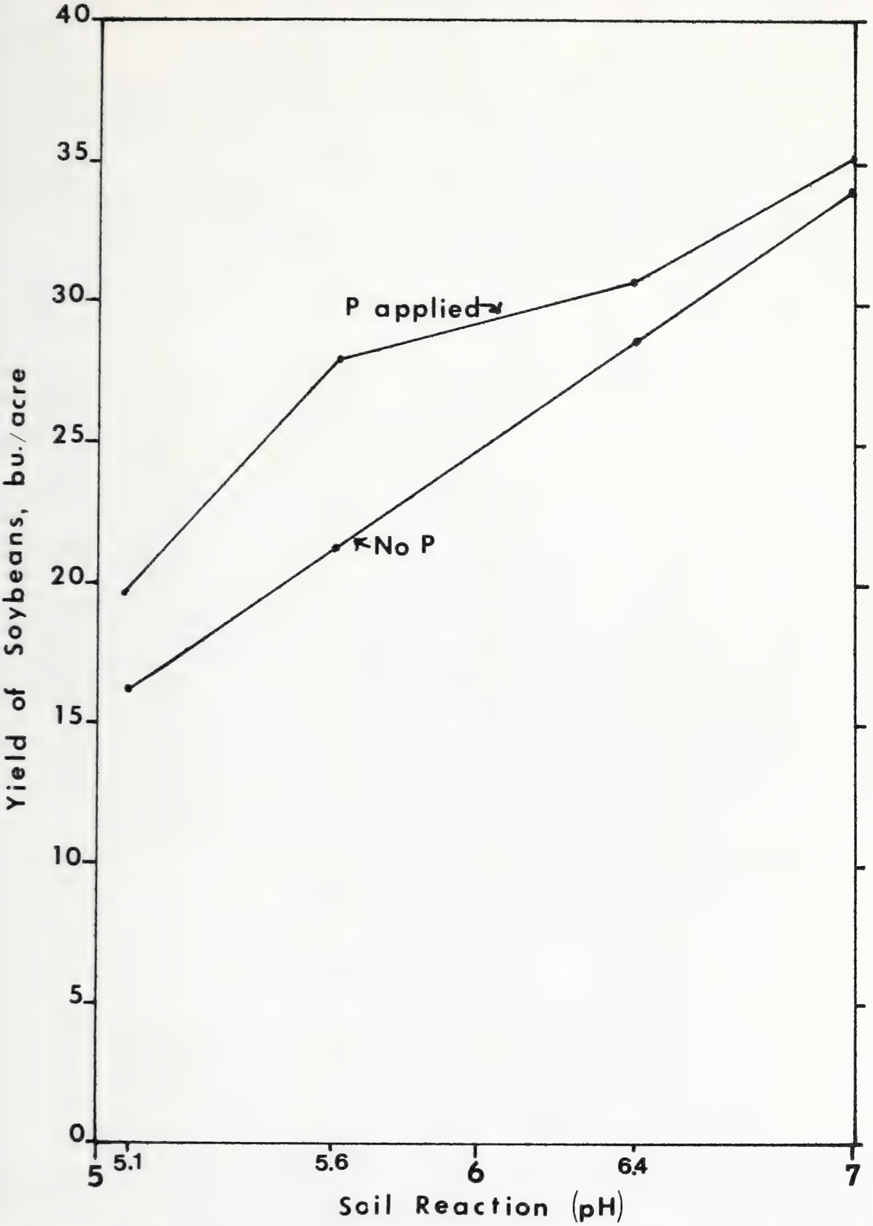

Figure 11.—Influence of soil reaction (pH) and applied P on the yield of Bienville soybeans grown on Olivier silt loam.

Summary

Soybean yields were low on Olivier silt loam soil at a soil pH of 5.1 at all soil phosphorus levels, with and without the use of fertilizer phosphorus. The best yields were 20 to 24 bushels per acre.

At pH 5.6 the yields with or without fertilizer phosphorus were 6 to 8 bushels higher than at pH 5.1. There was also more response to fertilizer phosphorus at pH 5.6, and most yields were in the 25- to 30-bushel range.

At pH 6.4 the yields without fertilizer phosphorus were considerably higher than at pH 5.6 or 5.1. The response to fertilizer phosphorus was less at pH 6.4 than at 5.6, but the yields were higher at 6.4.

The highest yields were produced at pH 7.0. The yields were higher at pH 7.0 without fertilizer phosphorus than they were with fertilizer phosphorus at any lower pH value. There was little or no response to fertilizer phosphorus at pH 7.0.

The effects of the additions of limestone on the yield of soybeans on Olivier silt loam soil were very outstanding. The data indicate that these soils should be limed to about pH 7.0, and that the extractable soil phosphorus level should be about 35 to 40 ppm for good soybean yields. Although response to fertilizer phosphorus may not be obtained at this soil phosphorus level, the use of small amounts of phosphorus may be desirable in order to help promote early growth and to maintain the soil phosphorus level.

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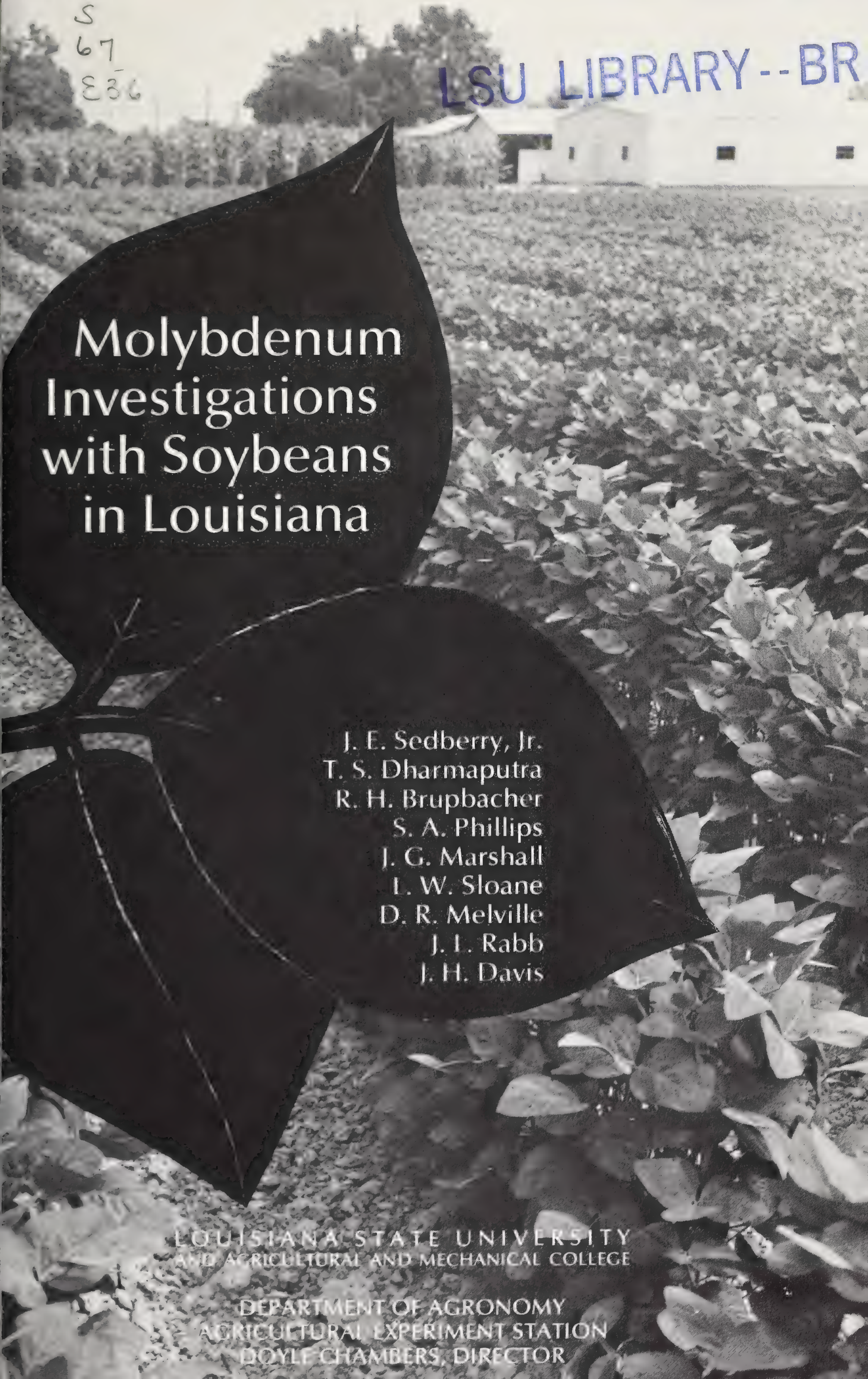

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INTRODUCTION

Molybdenum (Mo) is one of the eight micronutrient elements required for the growth and development of plants. Symptoms of Mo deficiency are known to exist in more than 40 higher plants (Hewitt, 1956). Its essentiality for plant growth was established over 30 years ago (Arnon and Stout, 1939). Since then, Mo deficiencies have been reported throughout the world, especially on acid soils in North America, Australia, and New Zealand (Anderson, 1956; Rubins, 1956).

During the past decade, reported incidences of Mo deficiences of certain crops grown on acid soils in the United States have increased significantly. In 1955, Mo deficiencies of crops grown under field conditions had been observed in only 13 states (Rubins, 1956). By 1962, the number of states reporting deficiencies had increased to 21 (Berger, 1962).

Since Mo is essential for symbiotic nitrogen fixation, Mo deficiency is frequently observed on legumes. However, deficiency has been noted on many other agronomic and horticultural plants. Crops that are classed as responsive to application of Mo under soil or environmental conditions favorable to a deficiency of the element are: cauliflower, broccoli, lettuce, onion, spinach, soybean, and clover (Lucas, 1967). Corn, cotton, rice, small grains, and grass are considered to be nonresponsive crops (Lucas and Knezek, 1972).

The relatively small fraction of the total Mo content of a soil that is considered to be "available" to the plant is dependent on the soil reaction (Hodgson, 1963; Leeper, 1970). Unlike most other micronutrient elements, Mo becomes relatively more "available" as the pH of the soil is increased. Therefore, responses to Mo added as fertilizer are greatest on acid soils and least on alkaline soils. The application of limestone to acid soils is an effective method of increasing the "availability" of soil Mo and the concentration of Mo in plants (Allaway, 1968).

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The rapid expansion of soybean acreage in Louisiana has resulted in the planting of this crop on many soils that are too acid for the profitable production of a legume crop. Soil test summaries indicate that 35 percent of the soils from all areas of the state, other than those in the Mississippi and Red River floodplains, had pH values below 5.5 (Brupbacher et al., 1970). There is a critical need for additions of limestone to adjust the reaction of the acid soils to pH 6.5 for the economical production of soybeans. Several investigators reported a yield response by soybeans to application of Mo on acid soils or on soils that were not adequately limed (Sedberry et al., 1966; deMooy, 1970; Keogh et al., 1971).

Soybeans and clover grown on a limited number of soils in Louisiana have shown responses in the production of dry matter to application of Mo under greenhouse conditions. In most cases, the responses attributed to Mo fertilization were obtained on soils that were acid in reaction. Greenhouse studies cannot be expected to indicate very accurately what would occur in the field under actual farming conditions.

The primary objectives of this investigation were: (1) to determine the effect of Mo fertilization on the yield of soybeans grown on soils under field conditions at different locations in the state, (2) to determine the effects of application of limestone and different rates and methods of application of Mo on the yield of soybeans, (3) to relate soil reaction (pH) and extractable soil calcium (Ca) to the response to applied Mo, and (4) to develop a method that might be used to predict a response by soybeans to applied Mo.

REVIEW OF LITERATURE

Molybdenum (Mo) may be present in soils in a number of different forms. It may occur as part of the mineral structure of soils, as an anion adsorbed by soil materials, and it may be bound with organic matter (Dobritskaya, 1961).

Davies (1956) classified soil Mo into four groups: (1) it may be held within the crystal lattice of primary and secondary minerals and is not available to plants; (2) it may be retained by clay minerals as the anion $MoO_4^=$, and the "availability" to higher plants is dependent upon soil reaction (pH) and probably the phosphate status; (3) molybdenum may also be a constitutent of soil organic matter; (4) a relatively small amount of the element may exist in the water soluble form.

Based on solubilities of the different oxides of Mo and the adsorption of the element by cotton seedlings, Amin and Joham (1958) suggested the following classification: (1) water-soluble Mo consisting largely of soluble salts which are considered available to plants; (2) ammonium hydroxide-soluble Mo which corresponds closely to the solubility of Mo trioxide, MoO_3. The MoO_3 is readily available to plants; (3) oxidizable Mo which is not available to plants, and whose solubility closely corresponds to the reduced oxides of Mo, MoO_2 and Mo_2O_5.

Molybdenum is generally found in soils in very small amounts. Although plants need only a very small amount of the micronutrient element, most of the Mo present in soils is held in an "unavailable" condition. This is especially true for acid soils, where most of the responses to Mo have been reported (Barshad, 1951; Mulder, 1954; Parker and Harris, 1962; James et al., 1968; Gupta, 1969). The total content of Mo in the soil does not reflect the amount "available" to plants, since a large part of the Mo is fixed in soil as insoluble sesquioxides of iron and aluminum (Leeper, 1970).

A considerable quantity of Mo may be present in organic matter. Some of the peat soils in Florida contain excessive amounts of Mo (Gammon et al., 1955). Grigg (1953) noted a correlation between loss on ignition of soils and Mo extracted with NaOH. His data suggested that a definite amount of Mo in soils was associated with the organic matter fraction.

The total Mo content in soils generally varies from 0.6 to 3.5 ppm (Evans and Purvis, 1951; Grigg, 1953; Robinson and Edington, 1954; Robinson et al., 1951). Some soils contain considerably larger amounts of total Mo than do others. An extremely large amount of total Mo, 31.5 ppm, was found by Robinson et al. (1951) in DeKalb silt loam. The large amount of Mo found in this soil was attributed to the high Mo content of the parent material.

According to Grigg (1953), the ammonium oxalate-extractable Mo content of several soils in New Zealand varied from 0.03 to 0.22 ppm. The water-soluble Mo content of soils is reported to be generally low. Gammon et al. (1955) determined soil Mo with different extracting solutions. The results showed that water-soluble Mo was lowest, ammonium hydroxide-soluble was highest, and nitric acid-soluble was intermediate.

The uptake of Mo by plants from a culture solution has been reported to be favored by an acid reaction (Stout et al., 1951). The effect of lime on decreasing the acidity of the soil, and in turn increasing the uptake of Mo by plants, is due to the effect of the lime in increasing the supply of "available" Mo in the soil, rather than to the physiological effect of soil reaction on the absorption of Mo by plants (Anderson, 1956).

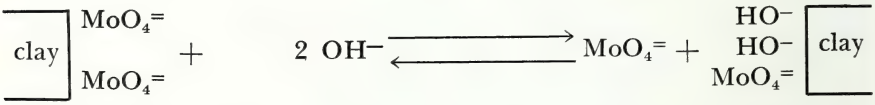
The practice of liming the soil to correct the Mo-deficiency disease commonly referred to as "whiptail" of cauliflower was known long before the true nature of the disease was discovered (Clayton, 1924). A disease in citrus, called "yellow spot," is also caused by Mo deficiency. This disease was first described by Stewart and Leonard (1952); it was corrected by liming. In soils where the total Mo content is low, liming may have a limited value in correcting Mo deficiency (Anderson, 1946). On some soils, responses to Mo were not obtained where lime had been applied (James et al., 1968).

Several investigators have demonstrated that application of lime to acid soils increases the Mo content of plant tissue (Barshad, 1951; Evans et al., 1951; Robinson et al., 1951; Giddens and Perkins, 1960; Welch and Anderson, 1962; James et al., 1968; Gupta, 1969; Gurly and Giddens, 1969). Robinson et al. (1951) reported that liming an acid soil to pH 7.0–7.6 increased the Mo content of ryegrass nearly as much as it did that of the legumes. James et al. (1968) obtained similar results with alfalfa grown under field conditions on acid soils in Oregon. With a low total Mo content in the soil, 0.60 ppm, Giddens and Perkins (1960) obtained only a slight increase in the Mo content of alfalfa as a result of adjusting the soil reaction from pH 5.5 to 6.3. Gupta (1969) also showed that liming the soil to pH 6.5 did not increase the Mo content of cauliflower, alfalfa, or bromegrass over 1.5 ppm.

It has been demonstrated by many workers that liming also increases the uptake of applied Mo (Ahlrichs et al., 1963; Evans et al., 1951; James et al., 1968).

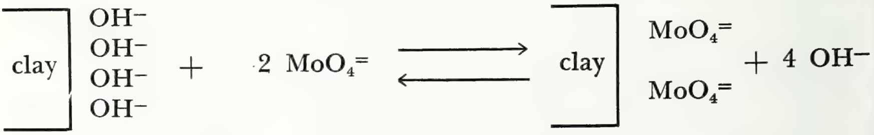
Only limited data are reported regarding the effect of lime on the uptake of Mo by soybeans. Nugent et al. (1967) reported an increase of both native and applied Mo in soybean leaves resulting from the application of limestone. Gurley and Giddens (1969) grew soybeans on two soils with three lime levels and varying levels of Mo applied to the seed and foliage. When the soil was limed to pH 6.5 and Mo was applied to the foliage, a high Mo content of the seed resulted.

According to Tisdale and Nelson (1966), the anion $MoO_4^=$ may be adsorbed by clays, and an increase in its availability with increasing pH values could be explained partly by the following equation:



$$\left.\text{clay}\right]\begin{matrix} MoO_4^= \\ \\ MoO_4^= \end{matrix} + 2\,OH^- \rightleftharpoons MoO_4^= + \begin{matrix} HO^- \\ HO^- \\ MoO_4^= \end{matrix}\left[\text{clay}\right.$$

Barshad (1951) showed that the removal of molybdate anions from the solution by acid clays was accompanied by an increase in the pH of the solution. He postulated that exchange between molybdate anions $MoO_4^=$ or HMo_4^-, and hydroxyl ions of the clay takes place in the soil in the same manner as phosphate ions. The following equation was used by Barshad (1951) to illustrate the reaction:



$$\left.\text{clay}\right]\begin{matrix} OH^- \\ OH^- \\ OH^- \\ OH^- \end{matrix} + 2\,MoO_4^= \rightleftharpoons \left.\text{clay}\right]\begin{matrix} MoO_4^= \\ \\ MoO_4^= \end{matrix} + 4\,OH^-$$

Amin and Joham (1958) proposed a Mo cycle in soils in which soluble

Mo salts were in equilibrium with less soluble Mo trioxide, MoO_3. The following illustration was used to show the equilibrium reaction:

$$\begin{tikzcd}
\text{Soluble Mo salt} \arrow[r, shift left] & MoO_3 \arrow[l, shift left] \arrow[rr, shift left] \arrow[dr, shift left] & & MoO_2 \arrow[ll, shift left] \arrow[dl, shift left] \\
& & Mo_2O_5 \arrow[ul, shift left] \arrow[ur, shift left] &
\end{tikzcd}$$

In acid soils, the equilibrium would be in favor of MoO_3. By increasing the pH, the equilibrium would shift to the left, forming soluble Mo salts, which results in a lowering of the amounts of slightly soluble MoO_3.

Several workers have reported that Mo uptake could be increased by the application of phosphorus (P) to a soil (Barshad, 1951; Stout et al., 1951; Mulder, 1954). According to Barshad (1951), the Mo content of Ladino clover was greatly increased by the application of phosphoric acid. Acidifying the soil with sulphuric acid, however, reduced the Mo content of clover.

Stout et al. (1951) also reported an increase in Mo uptake by subterranean clover that received an application of P. The increases were particularly evident when P and Mo were applied in combination. The Mo content in the plant tissue was increased ten- to thirtyfold over that of tissue of plants grown on soils that did not receive P.

Mulder (1954), working with soils in The Netherlands, found that the soils on which plants responded to added Mo were low in "available" P. An application of P alone to these soils exerted the same effect as did a Mo application. An application of Mo reduced the need of added P and resulted in the optimum growth of cauliflower.

There are only a few theories concerning the influence of P on the increased uptake of Mo. Davies (1956) proposed the possibility of an anion exchange effect in soils in which P replaced Mo which was held on the exchange complex. Since the uptake of Mo in water culture is similarly enhanced by P, another explanation is needed to explain the relationship betwen P and Mo. The relationship between the soil anions molybdate and phosphate may be associated with the formation of a complex phosphomolybdate anion which is absorbed more easily by the plant than the molybdate anion alone (Barshad, 1951).

Several workers have reported that the application of superphosphate depressed the Mo content of the plant (Gupta and Cutcliffe, 1968; Ouellette, 1963; Widdowson, 1966). Since superphosphate contains approximately 50% calcium sulphate, the depressing action of superphosphate on the uptake of Mo by crops may not be due to the phosphate ion, but rather to the sulphate ion (Stout et al., 1951).

In an experiment conducted under greenhouse conditions, sulphur (S) as ammonium sulphate was found to increase the yield and S content of Brussels sprouts and it sharply reduced the Mo content of the plant tissue (Gupta and Munro, 1969). When Mo was applied, S was much more effective in decreasing the Mo content of the plant tissue. Stout et al. (1951) reported that S applied as calcium sulphate decreased Mo absorption by tomatoes and peas. The data reported by Gupta and Munro (1969) and Stout et al. (1951) suggested that the sulphate ion was responsible for depressing the absorption of Mo by plants.

Walker et al. (1955) found that calcium sulphate reduced the yield of clovers, and this was attributed to the increased uptake of manganese (Mn), which resulted in an antagonism between Mn and Mo in the plant. The antagonistic effect was overcome by the application of Mo.

According to Reisenauer (1963), S fertilization apparently reduced the efficiency of utilization of Mo by the pea plant. This was especially true when low levels of Mo were found in the plant tissue. Reisenauer (1963) concluded that higher levels of Mo in plants are generally required for maximum yield, as the S content of the plant tissue is increased as the result of S fertilization.

The depressing effect of the sulphate ion on Mo uptake may be due to its acidifying action on the soil (Berger and Pratt, 1963). However, the main cause apparently lies in the physiological effect of sulphate in decreasing the Mo uptake in plant tissue. Since the $MoO_4^=$ anion is divalent and is the same size as the $SO_4^=$ anion, it is possible that these two anions may compete directly for absorption sites on the roots during the first step of absorption from the soil by plants (Stout et al., 1951). Gupta and Munro (1969) showed that relatively high rates of S did not change the pH of the soil and yet S had a depressing effect on the uptake of Mo.

Several attempts have been made to relate the Mo content of plants to yield (deMooy, 1970; James et al., 1968; Lavy and Barber, 1963; Melsted et al., 1969; Reisenauer, 1956). Reisenauer (1956) reported that there was a relationship between the yield of alfalfa and Mo content of the plant. He stated that an increase in the yield of alfalfa resulting from fertilization with Mo would not be expected when the Mo content of the leaves was greater than 0.4 to 0.5 ppm. James et al. (1968) reported that the critical level for Mo in alfalfa was from 0.3 to 0.5 ppm. Gupta and MacKay (1968) found significant positive relationships between the Mo content in plant tissue and the yield of plants grown in untreated soils.

According to Melsted et al. (1969), the critical value for Mo in the plant tissue of soybeans was 0.5 ppm. deMooy (1970), however, obtained yield responses to applications of Mo when leaf concentrations of Mo were far above the critical value reported by Melsted et al. (1969).

Lavy and Barber (1963) suggested that the Mo content of soybean seed would be a suitable indicator of the "available" Mo status of a soil. They found that when the Mo content of soybean seeds from untreated soils exceeded 1.6 ppm, little or no yield response was obtained from an application of Mo. According to Lavy and Barber (1963), the analysis of soybean seed for Mo has two advantages over the analysis of tissue samples from other parts of the plant. The relatively large amount of Mo in seeds assured more precision in measurement, and the analysis of mature seeds minimized differences in Mo contents due to differing stages of plant development.

The establishment of critical levels of Mo in plant tissue must be made with due consideration to the particular plant part analyzed. The physiological age of the different plant parts should also be taken into consideration. Reisenauer (1956) showed that the concentration of Mo in the leaves of alfalfa plants was approximately four times that of the stems. He also noted that wide variations in leaf-to-stem ratios had probably accounted for failures by some workers to obtain significant correlations between Mo analyses and fertilization rates.

Barshad (1951) demonstrated that the Mo content tends to increase with age of the plant, particularly during periods of slow growth. The level of other plant nutrient elements may also influence the relationship between the Mo content in plant tissue and the yield (Mulder, 1954; Reisenauer, 1963). When Mo deficiency limits growth by restricting symbiotic nitrogen fixation, the Mo content of legumes can be misleading (Ahlrichs et al., 1963).

Aspergillus niger had been used for the bioassay of "available" Mo in soils (Mulder, 1948; Nicholas and Fielding, 1951). The method is very sensitive and has been used to determine lower concentrations of Mo in plant tissue extracts and in plant ash than could be detected by chemical methods (Nicholas and Fielding, 1951). *Aspergillus niger* has the advantage that it is not subjected to certain interactions to the same extent as are higher plants (Mulder, 1954). Correlations between the "availability" of Mo to *Aspergillus niger* and to higher plants have also been noted (Mulder, 1948; Mulder, 1954).

A variety of chemical extractants have been used to determine the Mo content of soils (Barshad, 1951; Gammon et al., 1955; Grigg, 1953). According to Davies (1956), neutral normal ammonium acetate, normal ammonium acetate adjusted to pH 9 with NH_4OH, 1.0 *N* NH_4OH, water, 10 *N* HNO_3, and 10 *N* NH_4OH have been used to extract Mo. Grigg (1953) noted that responses to applications of Mo were obtained when the ammonium oxalate extractable Mo level of the soil was below 0.14 ppm, provided the soil reaction was below pH 6.3. Mueller et al. (1964) determined the extractable Mo content of 1,500 soil samples by the method proposed by Grigg (1953) and, by using pH + (10 x ppm Mo) as a yardstick, they found that the application of Mo stimulated growth of alfalfa when the value was 6.2 or less. When the calculated value was 8.2 or greater, application of Mo had no effect on the growth of alfalfa.

Gupta and MacKay (1968) stated that there was a significant relationship between the ammonium oxalate extractable Mo content of the soil and the yield of crops when Mo was not applied to the soil.

The importance of Mo for the fixation of gaseous nitrogen by *Azotobacter chroococcum* was first demonstrated by Bortels (1930). Later he showed that the growth and nitrogen fixation by peas, soybeans, and red clover were increased by an application of the element (Bortels, 1937).

Mulder (1948) studied the effect of Mo on N fixation by pea plants in culture solutions. He found that in the absence of Mo many nodules were formed, but the N-fixing capacity of the nodules was greatly reduced and this resulted in a poor N supply to the plants. Hangstrom and Berger (1963) reported that application of Mo increased the nodulation and N content of soybeans and peas.

Bond and Hewitt (1961), working with *Myrica* grown in culture solution, demonstrated the effectiveness of N fixation in the nodules of plants supplied with Mo. Plants supplied with Mo fixed 383 mg of N per gram of nodule dry matter formed, whereas the corresponding value for plants that were Mo deficient was only 83 milligrams.

Steinberg (1936) presented evidence indicating that Mo had a specific function in *Aspergillus niger* that was not associated with N fixation. The work of Mulder (1948) confirmed the essentiality of Mo for the utilization of nitrate by *Aspergillus niger* as well as by the green plants. His results indicated that Mo is indispensable for the reduction of nitrate in tomato plants. In the absence of Mo, NO_3-N accumulated in the tomato leaves and there were very small amounts of soluble organic N compounds and proteins formed. Mulder (1948) conducted another experiment which showed that Mo was essential for the first step of NO_3 assimilation, which involved the reduction of NO_3^- to NH_4^+. The leaves of tomato plants that were deficient in Mo and supplied with NO_3-N were yellow-green in color, while the addition of NH_4-N resulted in the formation of dark green leaves. The chemical analysis of the leaf tissue indicated that the plants receiving NO_3-N in the absence of Mo contained more than 30 times as much NO_3^- as did the ones supplied with Mo. The content of organic N was also higher in the plants that received NH_4-N than in those that received NO_3-N. The research conducted by Mulder (1948) indicated that without Mo the formation of organic N from ammonia could not take place.

Evans et al. (1950) obtained similar results with alfalfa plants, and their research indicated that legumes also required Mo for the reduction of NO_3^-.

EXPERIMENTAL PROCEDURE

The research reported here was conducted during an 8-year period, 1964-1971. Thirty-four field experiments were conducted at 22 locations in Louisiana. The experiments were located on soils in the major soybean-producing areas of the state. The soil type, location, cooperator, type of experiment, and the method of applying molybdenum are presented in Table 1. For the purpose of identification and convenience in reporting, each soil and experimental location was arbitrarily assigned a number from 1 to 22.

The design of the experiments involving the application of limestone and molybdenum (Mo), experiments 1, 2, 21, and 22, was a split-plot arrangement, with the limestone treatments occupying the main plots and the Mo treatments occupying the sub-plots. Two rates of limestone, none and 2 tons per acre, were used on Beauregard silt loam in Allen Parish, experiment 1. The rates of limestone applied to Calhoun silt loam–experiment 2 and to Crowley silt loam–experiment 21 were none, 2, and 4 tons per acre. Twelve replications of each of the two limestone treatments were used on the Beauregard silt loam. The three limestone treatments were replicated four times each on the Calhoun silt loam and on the Crowley silt loam. The design of the lime and Mo experiment on Wrightsville silt loam in Jeff Davis Parish, experiment 22, was a simple randomized block with four replications each of lime and molybdenum and the combination of the two treatments. High grade calcitic limestone served as the source of lime in all of the experiments. The liming material was broadcast on the surface of the soil and thoroughly incorporated into the top 4 inches by disking prior to planting soybeans.

With the exception of the experiment conducted on the Beauregard soil in Allen Parish, experiment 1, each of the limed plots was composed of 16 rows 3 1/3 feet wide and 100 feet long. In the Allen Parish experiment the limed plots contained eight rows 3 feet wide and 200 feet long.

Sodium molybdate, $Na_2MoO_4 \cdot 2H_2O$, containing 39.65% Mo, served as the source of the element in all of the experiments. The methods of applying Mo consisted of a seed, foliar, and soil treatment. A Mo seed treatment was used at each of the 22 locations. In addition to the seed treatment, a foliar and a soil treatment were employed on Calhoun silt loam–experiment 2, on Norwood silt loam–experiment 4, on Yahola silt loam–experiment 6, and on Crowley silt loam–experiment 21. A soil application of Mo was also made to Wrightsville silt loam in Jeff Davis Parish.

In all of the experiments conducted from 1964 to 1967, the rate of Mo used as a seed treatment was 0.5 ounce (14.18 g) per acre. After the 1967 growing season, the rate of Mo used on the soybean seed was reduced to 0.25 ounce per acre because of an apparent toxicity encountered at two locations following application at the higher rate. The soybean seed treatment consisted of applying the Mo compound in 100 g of water to 1 bushel of seed prior to inoculation and immediately before planting. The seed and the combination of Mo and inoculum were thoroughly mixed to insure that each seed was uniformly coated with the mixture. The rate and method of applying Mo to the foliage was: 3 ounces of Mo per acre in a water solution sprayed on the foliage as a

Table 1.—Soil type, location, cooperator, type of experiment, and method of applying molybdenum in the field experiments, 1964-1971

Exp. No.	Soil type[1]	Location (parish)	Cooperator[2]	Type of experiment	Method of applying Mo	Year (s)
1	Beauregard sil[3]	Allen	H. D. Dear	Lime x Mo	seed	1964
2	Calhoun sil	Franklin	Macon Ridge Branch Exp. Sta.	Lime x Mo	seed, foliar, soil	1965-70
3	Gallion sil	St. Landry	N. Dubuisson	Mo	seed	1965
4	Norwood sil	Rapides	Dean Lee Ag. Center	Mo	seed, foliar, soil	1965-69
5	Olivier sil	W. Carroll	J. Y. Smith	Mo	seed	1965
6	Yahola vfsl	Bossier	Red River Valley Exp. Sta.	Mo	seed, foliar, soil	1965-67
7	Gallion vfsl	Caldwell	E. C. McGee	Mo	seed	1966
8	Acadia sil	J. Davis	Seward LeJeune	Mo	seed	1966
9	Jeanerette sil	Evangeline	Huey Fontenot	Mo	seed	1966
10	Beauregard sil	Beauregard	Bill Habetz	Mo	seed	1966
11	Crowley sil	St. Landry	Bruce Brown	Mo	seed	1966
12	Crowley sil	Allen	T. H. Mayes	Mo	seed	1966
13	Mantachie fsl	Catahoula	C. E. Myers, Jr.	Mo	seed	1966
14	Calhoun sil	Franklin	J. B. Eley	Mo	seed	1966
15	Robinsonville fsl	Tensas	Warren Clark	Mo	seed	1966
16	Alligator clay	Catahoula	La. Delta Plantation	Mo	seed	1967
17	Perry clay	Morehouse	A. R. McGinty	Mo	seed	1967
18	Olivier sil	Rapides	George Tuma	Mo	seed	1967
19	Chastain clay	Union	T. L. James & Co.	Mo	seed	1967
20	Commerce sil	Tensas	N. E. La. Exp. Sta.	Mo	seed	1966-67
21	Crowley sil	Acadia	Rice Exp. Station	Lime x Mo	seed, foliar, soil	1966-67
22	Wrightsville sil	J. Davis	Sherman Fontenot	Lime x Mo	seed, soil	1971

[1] The soils were classified by S. A. Lytle, Associate Professor, Louisiana Agricultural Experiment Station.

[2] The cooperators were selected by Cooperative Extension personnel in each of the parishes.

[3] Sil = silt loam; fsl = fine sandy loam; vfsl = very fine sandy loam.

split application—1.5 ounces applied when the soybeans were approximately 10 inches tall and the remaining 1.5 ounces when the soybeans were in full bloom. The application of Mo to the soil was made by dissolving the equivalent of 0.5 pound of Mo per acre in 10 gallons of water and spraying the mixture broadcast on the soil surface prior to planting.

With the exception of experiment 1 on Beauregard silt loam in Allen Parish, each Mo plot consisted of four rows 40 inches wide and 100 feet long. In the Allen Parish experiment, the rows were 36 inches wide and 200 feet long. On plots that received Mo, all four rows were treated. In order to minimize the possibility of border effect, the two center rows of each plot were harvested for yield measurements. Soybeans grown on all of the experiments were mechanically harvested and the yield was reported in bushels per acre corrected to 13% moisture.

Prior to the initiation of the field experiments representative surface soil samples were collected from each of the 22 experimental locations. To eliminate the possibility of contamination with Mo and other plant nutrient elements, all soil samples were collected and stored in 18-ounce plastic bags.

Extractable P, K, Ca, and Mg and soil reaction (pH) were determined on all of the soil samples by the method outlined by Brupbacher et al. (1968). The organic matter content of the soil was determined by the chromic acid method reported by Walkley and Black (1934).

The cation exchange capacity of the soils was determined with ammonium acetate adjusted to pH 7.0 as described by Jackson (1958). The exchangeable cations, Ca, K, Mg, and Na, were determined on a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer.

The total Mo content of the soils was determined by the thiocyanate method using isopropyl ether as an organic extractant as suggested by Purvis and Peterson (1956), after digesting the soil with perchloric acid as described by Reisenauer (1956).

Ammonium oxalate adjusted to pH 3.3 with oxalic acid was used to determine the extractable Mo content of each soil. The extracting solution was prepared by dissolving 24.9 grams of ammonium oxalate and 12.605 grams of oxalic acid in a liter of distilled water. A soil to extracting solution ratio of 1:10 was used. A 25-gram sample of soil and 250 milliliters of extracting solution were agitated for 8 hours on a mechanical shaker and allowed to stand overnight before filtering. Gorlach (1964) reported that a shaking time of 2 hours and standing time of 20 hours was sufficient for extracting Mo except on heavy-textured soils that contained high amounts of the element.

The suspension of the soil and extracting solution was filtered through Whatman No. 42 filter paper. A 100-milliliter aliquot of the filtrate was evaporated to dryness on a hot plate. The residue was placed in a muffle furnace at 450C for 4 hours to destroy organic matter. The residue was dissolved in 20 milliliters of 6.5 *N* HCl, refiltered, and diluted to a final volume of 75 milliliters.

After the addition of a 10% solution of ammonium thiocyanate and a solution of sodium nitrate and stannous chloride, a brownish-yellow to orange color developed. Isopropyl ether was used to separate and concentrate the Mo thiocyanate color complex.

According to Purvis and Peterson (1956), the formation of orange-colored Mo-thiocyanate complex is produced in HCl in the presence of a reducing agent. The colored complex can be extracted in ether or other suitable solvents and the intensity of the color developed is proportional to the concentration of Mo.

The intensity of the Mo-thiocyanate color complex formed was measured on a Bausch and Lomb Spectronic 20 colorimeter. The amount of Mo in the soil solution extract was determined by reference to a calibration curve obtained by plotting the optical density reading with the Mo concentration of the standards.

Soybean leaves from each plot at the 22 experimental locations were sampled when the plants were in the early bloom stage of growth. The first mature leaf from the top of the plant was selected for the chemical analysis. Twenty fully-matured leaves from plants growing on each plot were taken at random. The soybean leaves were placed in cloth bags and dried in a forced draft oven at 70C. After drying for 24 hours, the leaves were ground in a Wiley mill to pass a 20-mesh sieve and stored in 4-ounce wide-mouth specimen bottles. The concentration of Mo in the leaves was determined by dry ashing a 2-gram sample of plant material in a muffle furnace at 550C for 4 hours. The ash was dissolved in 6.5 *M* HCl containing 0.5 gram of $FeCl_3 \cdot 6H_2O$ per liter and filtered through Whatman No. 42 filter paper. The method for determining the Mo content of the plant tissue was identical with the one followed in the analysis of the soil. The Beckman Model DU Spectrophotometer was used to measure the Mo concentration in the plant tissue.

The following equation proposed by Mueller et al. (1964) was used to predict a yield response by soybeans to application of Mo: Soil reaction (pH) + (10 x ppm extractable Mo).

The yield data and the soil and the plant chemical analytical data were statistically analyzed by the analysis of variance method described by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Chemical properties of the surface soils used in the molybdenum investigations are presented in Table 2. The textural classes of the soils were very fine sandy loams, fine sandy loams, silt loams, and clays. The extractable P contents of the two Beauregard silt loams–experiments 1 and 10, the two Crowley silt loams–experiments 12 and 21, and

Table 2.—Chemical properties of the soils used in the Mo investigations

Experiment number	Soil type	Extractable[1]				Organic matter
		P	K	Ca	Mg	
		ppm				%
1	Beauregard sil	20	114	272	120	1.73
2	Calhoun sil	90	170	390	139	0.63
3	Gallion sil	138	126	470	235	0.55
4	Norwood sil	253	105	5,820	1,400	0.85
5	Olivier sil	74	113	418	134	0.78
6	Yahola vfsl	296	175	1,570	387	0.56
7	Gallion vfsl	180	125	270	105	0.48
8	Acadia sil	30	49	470	81	1.51
9	Jeanerette sil	48	85	980	195	1.48
10	Beauregard sil	14	60	640	268	1.24
11	Crowley sil	49	75	750	182	1.19
12	Crowley sil	5	40	470	143	1.23
13	Mantachie fsl	41	120	1,400	268	0.58
14	Calhoun sil	21	90	340	75	1.15
15	Robinsonville fsl	157	180	1,140	170	1.76
16	Alligator clay	63	313	3,570	656	3.17
17	Perry clay	25	330	3,040	813	4.32
18	Olivier sil	44	114	560	130	1.22
19	Chastain clay	15	151	750	174	8.10
20	Commerce sil	220	140	1,280	326	1.29
21	Crowley sil	9	71	770	194	1.33
22	Wrightsville sil	40	41	340	62	1.06

[1] Phosphorus was extracted with 0.1 normal hydrochloric acid containing 0.03 normal ammonium fluoride at a soil to extracting solution ratio of 1:20. Potassium, calcium, and magnesium were extracted with 0.1 normal hydrochloric acid at a soil to extracting solution ratio of 1:20.

the Chastain clay—experiment 19 were considered to be low for high yields of soybeans. The Acadia silt loam—experiment 8, the Crowley silt loam—experiment 12, and the Wrightsville silt loam—experiment 22 contained relatively low contents of extractable K. Concentrated superphosphate, 20.2% P, and potassium chloride, 49.8% K, were applied at a rate equivalent to 50 pounds each of P_2O_5 and K_2O to the soils that contained low levels of P and/or K. The Ca contents of the soils varied from 270 ppm on Gallion very fine sandy loam—experiment 7, to 5,820 ppm on Norwood silt loam—experiment 4. Calcium levels of less than 500 ppm, 1,000 ppm, and 2,400 ppm for the coarse-, medium-, and fine-textured soils, respectively, were considered to be marginal for high yields of soybeans. The Mg contents of the soils ranged from 62 ppm on the Wrightsville silt loam—experiment 22 to 1,400 ppm on the Norwood silt loam—experiment 4. The Mg levels in all of the soils were considered to be adequate for the production of soybeans. Relatively high amounts of organic matter were found in the Alligator clay—experiment 16, the Perry clay—experiment 17, and the Chastain clay—experiment 19. These three soils were representative of recently-cleared forested areas and they had been in cultivation only a short time prior to the initiation of the Mo investigations. Seven of the 22 soils contained less than 1% organic matter.

The cation exchange capacity, base saturation, soil reaction (pH), and the total and extractable Mo contents of the soils are presented in Table 3. The cation exchange capacities varied from 5.61 meq per 100 grams of soil for the Beauregard silt loam to 51.65 meq per 100 grams of soil for the Alligator clay. The cation exchange capacities of Norwood silt loam, Robinsonville fine sandy loam, Alligator clay, Perry clay, Chastain clay, Commerce silt loam, and Crowley silt loam–experiment 21 were considerably higher than were the cation exchange capacities of the remaining soils. The base saturation of the soils varied from 19.7% for the Chastain clay to 100% for the Norwood silt loam. The soil reaction ranged from pH 4.2 for the Alligator clay to pH 7.6 for the Norwood silt loam. A highly significant positive correlation coefficient $(r = 0.891)$

Table 3.—The cation exchange capacity, percent base saturation, soil reaction, and the total and extractable Mo contents of the soils

Experiment number	Soil type	Cation exchange capacity	Base saturation	Soil reaction	Total[1] Mo	Extractable[2] Mo
		meq/100g	%	pH	ppm	
1	Beauregard sil	5.61	41.0	5.4	0.63	0.07
2	Calhoun sil	9.27	35.5	5.1	1.60	0.17
3	Gallion sil	5.57	59.8	5.3	0.87	0.15
4	Norwood sil	22.83	100.0	7.6	1.30	0.04
5	Olivier sil	8.28	36.3	5.1	1.31	0.16
6	Yahola sil	9.67	97.6	7.1	0.98	0.03
7	Gallion vfsl	7.47	26.6	4.9	0.75	0.04
8	Acadia sil	8.10	41.2	5.7	1.13	0.05
9	Jeanerette sil	8.99	43.3	5.4	1.50	0.14
10	Beauregard sil	8.03	54.1	5.7	1.61	0.12
11	Crowley sil	11.08	38.8	5.5	1.60	0.14
12	Crowley sil	10.35	40.2	5.6	1.64	0.18
13	Mantachie sil	6.95	21.4	5.4	0.88	0.22
14	Calhoun sil	11.62	38.1	4.9	0.78	0.21
15	Robinsonville fsl	18.46	67.5	6.2	1.62	0.18
16	Alligator clay	51.65	46.6	5.1	1.43	0.42
17	Perry clay	41.50	44.8	5.4	1.65	0.23
18	Olivier sil	10.20	46.2	5.6	1.60	0.19
19	Chastain clay	44.53	19.7	4.2	1.52	0.38
20	Commerce sil	24.20	60.7	6.4	1.30	0.22
21	Crowley sil	18.40	39.1	5.9	1.19	0.14
22	Wrightsville sil	6.52	37.8	5.1	1.55	0.12

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[1] The total Mo was determined after digesting the soils with $HClO_4$ by the thiocyanate method using isopropyl ether as the organic extractant.

[2] The Mo was extracted with ammonium oxalate adjusted to pH 3.3 with oxalic acid. A soil to extracting solution ratio of 1:10 was used. The extracting time was 8 hours.

was found between base saturation and the soil reaction (pH) of all of the soils. The total Mo content of the soils ranged from 0.63 ppm for the Beauregard silt loam–experiment 1, to 1.65 ppm for the Perry clay. The Beauregard silt loam–experiment 1, the Gallion silt loam–experiment 3, the Gallion very fine sandy loam–experiment 7, and the Calhoun silt loam–experiment 14 contained less than 1 ppm of total Mo. The extractable Mo contents of the soils varied from 0.03 ppm for the Yahola silt loam to 0.42 ppm for the Alligator clay. The Beauregard silt loam, the Norwood silt loam, the Yahola silt loam, the Gallion very fine sandy loam–experiment 7, and the Acadia silt loam contained significantly smaller amounts of extractable Mo than did the other soils.

The relationships as shown by correlation coefficients (r) between extractable and total Mo contents and certain chemical properties of the soils are presented in Table 4. Significant positive correlations were found between extractable Mo and extractable K, organic matter, and cation exchange capacity. A significant negative correlation ($r = -0.502$) was found between soil reaction (pH) and the extractable Mo content of the soils. The data indicated that as the soil reaction increased from pH 4.9 to pH 7.6, there was a corresponding decrease in the amount of Mo extracted from the soils. Greenhouse and laboratory investigations indicated that the ammonium oxalate-oxalic acid extractant adjusted to pH 3.3 did not remove the Mo that was "available" to the soybean plants grown on the Norwood silt loam, the Yahola silt loam, the Robinsonville fine sandy loam, or the Crowley silt loam. The data suggested that the ammonium oxalate-oxalic acid extractant may not be a suitable extractant for Mo on soils that have relatively high exchange capacities. Significant relationships were not found between the total and extractable Mo contents of the soils. The total Mo content of the soils was not related to any of the other soil chemical properties.

Table 4.—The relationships as shown by correlation coefficients (r) between extractable and total Mo contents and certain chemical properties of the soils

Chemical property	Extractable Mo (r)	Total Mo (r)
Extractable P	–0.364	–0.223
Extractable K	0.523*	0.125
Extractable Ca	0.122	0.150
Extractable Mg	0.026	0.128
Organic matter	0.665**	0.311
Cation exchange capacity	0.747**	0.342
Base saturation	–0.388	0.008
Soil reaction, pH	–0.502*	–0.002
Extractable Mo		0.347
Total Mo	0.347	

*Denotes a significant difference at the 5% level of probability.
**Denotes a significant difference at the 1% level of probability.

The influence of soil reaction (pH) on the yield response by soybeans to the application of Mo is presented in Table 5 and illustrated in Figure 1. The data showed that the yield response by soybeans to application of Mo decreased as the soil reaction increased from pH 4.9 to pH 7.0. The largest increase in the yield of soybeans attributed to the Mo treatment, 11.7 bushels per acre, was obtained on Gallion very fine sandy loam with a pH of 4.9 in Caldwell Parish. The application of Mo to Calhoun silt loam, pH 4.9, experiment 14, resulted in an increase in yield of only 1 bushel per acre. The Calhoun silt loam contained an excessive or toxic amount of Mn and this condition may have resulted in a lower yield and a smaller response to the Mo treatment. The leaves of the soybean plants grown on the Calhoun soil were "crinkled" and appeared to be smaller than normal. The affected leaves curved downward at the tip and some developed a yellow color between the veins. The yellowing of the interveinal tissue began at the tip of the leaf and progressed toward the base of the leaf. The data presented in Figure 1 indicate that at a soil pH of 5.0, the application of Mo resulted in an

Table 5.—The influence of soil reaction (pH) on the yield response by soybeans to the application of Mo

Experiment number	Soil type	Location	Soil reaction	Increase from application of Mo
		parish	pH	bu./acre
14	Calhoun sil	Franklin	4.9	1.0
7	Gallion vfsl	Caldwell	4.9	11.7*
17	Perry clay	Morehouse	5.1	1.1
5	Olivier sil	W. Carroll	5.1	1.3
2	Calhoun sil	Franklin	5.1	7.4*
22	Wrightsville sil	Jeff Davis	5.1	8.2*
3	Gallion sil	St. Landry	5.3	1.0
13	Mantachie sil	Catahoula	5.4	1.3*
9	Jeanerette sil	Evangeline	5.4	2.5*
1	Beauregard sil	Allen	5.4	3.4*
11	Crowley sil	St. Landry	5.5	2.2*
18	Olivier sil	Rapides	5.6	1.2
12	Crowley sil	Allen	5.6	1.4*
8	Acadia sil	Jeff Davis	5.7	6.2*
10	Beauregard sil	Beauregard	5.7	2.2*
21	Crowley sil	Acadia	5.9	0.0
1	Beauregard sil	Allen	6.0	1.7*
15	Robinsonville sil	Tensas	6.2	0.0
2	Calhoun sil	Franklin	6.2	1.1
1	Beauregard sil	Allen	6.4	0.0
20	Commerce sil	Tensas	6.4	0.0
2	Calhoun sil	Franklin	7.0	0.0
6	Yahola sil	Bossier	7.1	0.0
4	Norwood sil	Rapides	7.6	0.0

*Denotes significance at the 5% level of probability.

average increase in yield of approximately 4.8 bushels of soybeans per acre. An increase of approximately 2.6 bushels per acre was obtained following the application of Mo to soils with a pH of 5.5. An average increase of only 1 bushel per acre was obtained from the Mo treatment when the soil reaction was pH 6.0. A significant increase in yield from the application of Mo was not obtained when the soil reaction was 6.2 or higher.

The influence of limestone and Mo on the yield of soybeans grown on Beauregard silt loam–experiment 1 is shown in Table 6. The data indicate that significantly higher soybean yields were obtained on limed plots, irrespective of the Mo treatments. Application of Mo resulted in increased yields, regardless of the limestone treatment. The highest yield, 32.2 bushels per acre, occurred on limed soils that received Mo. Only 26.7 bushels of soybeans were produced on unlimed soils that did not receive Mo. There was no significant interaction between limestone and Mo. The application of limestone and Mo had no effect on oil or protein content of the soybeans. The beans contained 18.3% oil and 40.0% protein, regardless of the treatment.

Soybean seed weights as influenced by the limestone and Mo treatments are presented in Table 7. Higher seed weights were obtained on limed soils, regardless of the Mo treatment. Mo increased the weight of soybean seeds, whether or not limestone was applied.

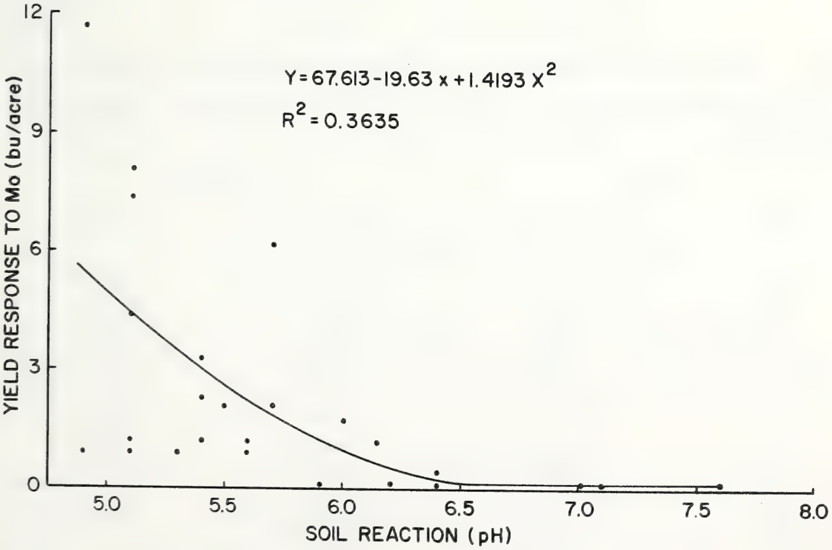

Fig. 1.—The influence of soil reaction (pH) on the yield response by soybeans to the application of Mo on 22 soils.

Table 6.—The effects of additions of limestone and Mo on yield of Bienville soybeans grown on Beauregard silt loam, H. D. Dear farm, Allen Parish, 1964

	Limed[1]		Nonlimed	
	Mo	No Mo	Mo[2]	No Mo
	— — — — — — —	bushels per acre	— — — — — —	
	35.0	31.5	34.6	30.5
	35.3	33.2	32.1	31.6
	31.6	31.5	28.3	25.8
	28.3	26.6	24.9	22.5
	28.6	26.0	24.0	21.7
	25.5	24.1	23.2	22.8
	31.8	32.3	29.9	28.7
	31.6	31.1	29.8	26.0
	34.4	34.8	32.2	27.5
	35.5	30.7	33.9	26.6
	34.2	32.4	32.1	28.4
	34.5	31.8	36.1	28.7
Avg.	32.2	30.5	30.1	26.7

[1] Two tons of calcitic limestone per acre were applied on April 10, 1964. Initially the untreated soil had a pH of 5.4. The soil contained 20 ppm P, 114 ppm K, 272 ppm Ca, and 120 ppm Mg. The organic matter content was 1.73%.

[2] Mo as sodium molybdate, ($Na_2MoO_4 \cdot 2H_2O$) 39.65% Mo, was applied at a rate of 0.5 ounce Mo per acre. Soybean seeds were treated with Mo prior to inoculation.

Cooperators: Hanson Firmin, County Agent, C. H. Jordan, Associate County Agent, and Olen D. Curtis, Associate Specialist (Agronomy), L.S.U.

Table 7.—The effects of additions of limestone and Mo on seed weight of Bienville soybeans on Beauregard silt loam, H. D. Dear farm, Allen Parish, 1964

	Limed		Nonlimed	
	Mo	No Mo	Mo	No Mo
	— — — — —	weight in grams, 100 seed	— — — — —	
	15.88	15.52	15.60	15.70
	16.39	16.50	14.86	14.96
	15.13	15.16	16.06	14.62
	16.86	14.38	15.20	13.54
	14.51	15.76	14.69	14.24
	15.94	16.10	14.76	13.08
	16.55	16.10	16.45	15.23
	16.10	15.98	15.92	15.00
	15.62	15.86	15.84	14.93
	16.50	16.28	15.86	15.49
	16.20	15.20	16.04	14.42
	16.48	16.19	16.24	14.72
Avg.	16.01	15.75	15.63	14.66

Seed weights were determined by Mr. D. B. Johnson, State Department of Agriculture and Immigration, Seed Testing Laboratory.

In 1965, field investigations involving different rates and methods of application of Mo for soybeans were conducted on five soil types in Louisiana. The soils at the experimental locations were Calhoun silt loam in Franklin Parish, experiment 2; Gallion silt loam in St. Landry Parish, experiment 3; Norwood silt loam in Rapides Parish, experiment 4; Olivier silt loam in West Carroll Parish, experiment 5; and Yahola very fine sandy loam in Bossier Parish, experiment 6. Experimental locations, soil types, treatments, and yields are shown in Table 8. The relatively low yield occurring on Calhoun silt loam in Franklin Parish, irrespective of Mo treatment, was attributed in part to dry weather when soybeans were developing pods. The highest soybean yield, 64.2 bushels per acre, occured on Yahola very fine sandy loam in Bossier Parish that received 0.5 pound of Mo per acre as a broadcast soil application. The differences in yield from the Mo treatments on any one soil were not statistically significant.

Table 8.—Effect of Mo applied to soybeans on different soils in Louisiana, 1965

Location (Parish)	Soil type	Mo treatment[1]			
		Check	Seed	Foliar	Soil
		— — — yield,	bushels	per acre —	— —
Franklin	Calhoun sil	14.1	15.6	15.6	13.4
St. Landry[2]	Gallion sil	35.7	36.7		
Rapides	Norwood sil	33.9	33.5	33.9	34.1
W. Carroll[2]	Olivier sil	31.5	32.8		
Bossier	Yahola vfsl	58.2	61.7	59.6	64.2

[1] One-half ounce Mo/A. applied to seed, 3 ounces Mo to foliage, and 0.5 pound to soil.

[2] Experiments conducted in cooperation with N. Dubuisson, farmer, and J. J. Robert, Associate County Agent, St. Landry Parish, and J. Y. Smith, farmer, and S. C. Ferguson, Associate County Agent, West Carroll Parish.

Four field investigations involving different rates and methods of application of Mo for soybeans were conducted on four different soils in Louisiana in 1966. The soils and experimental locations were: Norwood silt loam at the Dean Lee Agricultural Center, experiment 4; Commerce silt loam at the Northeast Louisiana Experiment Station, experiment 20; Yahola very fine sandy loam at the Red River Valley Experiment Station, experiment 6; and Crowley silt loam at the Rice Experiment Station, experiment 21.

Experimental locations, soil types, treatments, and yields are presented in Table 9. The differences in yield from Mo treatments on any one soil were not significant. Higher but nonsignificant increases in yield have been noted from all Mo treatments on Yahola very fine sandy loam at the Red River Valley Experiment Station. The highest yield, 50.8 bushels per acre, occurred on the Yahola soil when soybeans received 3 ounces of Mo as a foliar spray.

Table 9.—The effects of different rates and methods of applying Mo on the yield of soybeans grown on different soils and locations in Louisiana, 1966

Experiment location	Soil type	Mo treatment Check	Seed[1]	Foliar[2]	Soil[3]
		— bushels of soybeans per acre —			
Dean Lee Agricultural Center	Norwood sil	41.1	41.3	40.5	40.6
N.E. La. Exp. Sta.	Commerce sil	48.2	47.7	—	—
R. R. Valley Exp. Station	Yahola vfsl	47.3	48.4	50.8	48.4
Rice Exp. Station	Crowley sil	44.6	43.0	44.4	44.3

[1] One-half ounce of Mo applied to seed prior to inoculation before planting.

[2] Three ounces of Mo applied as foliar spray—1½ ounces applied after soybeans were up to a stand and the remainder when plants were blooming.

[3] One-half pound of Mo applied as a broadcast treatment to the soil.

The effect of Mo on the yield of soybeans grown at the nine outfield locations in Louisiana in 1966 is presented in Table 10. A significant increase in yield resulted from the addition of Mo at six of the nine locations. The largest increase, 11.7 bushels per acre, occurred on Gallion silt loam in Caldwell Parish. The soil pH was 5.2 and the dilute acid-extractable calcium was 510 ppm. Significant yield increases were also recorded on Acadia silt loam, Jeanerette silt loam, Beauregard silt loam, and Crowley silt loam.

Table 10.—The effect of Mo on the yield of soybeans grown at nine outfield locations in Louisiana, 1966[1]

Location (Parish)	Soil type[2]	Soil Ca ppm	Soil pH	Yield in bushels per acre No Mo	Mo[3]	Increase from Mo
Caldwell	Gallion sil	510	5.2	35.2	46.9	11.7*
Jeff Davis	Acadia sil	430	5.7	28.3	34.5	6.2*
Evangeline	Jeanerette sil	980	5.4	42.3	44.8	2.5*
Beauregard	Beauregard sil	640	5.7	37.6	39.8	2.2*
St. Landry	Crowley sil	980	6.2	33.2	35.4	2.2*
Allen	Crowley sil	470	5.6	27.7	29.1	1.4*
Catahoula	Mantachie fsl	1,400	5.4	44.4	45.7	1.3
Franklin	Calhoun sil	340	4.9	20.7	21.7	1.0
Tensas	Robinsonville vfsl	1,140	6.2	57.0	55.7	– 1.3

*The differences in yield from the use of Mo were statistically significant at the 5% level of probability.

[1] The experiments were conducted in collaboration with the following personnel of the Louisiana Cooperative Extension Service: Donald Hollis, Gilbert Martin, C. J. Tassin, H. E. Deere, J. J. Robert, Hanson Firmin, E. E. Johnson, A. W. Johnson, and C. B. James.

[2] Soils classified by S. A. Lytle, Louisiana Agricultural Experiment Station.

[3] Mo at the rate of 0.5 ounce per acre as $Na_2MoO_4 \cdot 2H_2O$, containing 39.65% Mo, was mixed with the seed immediately before inoculating and planting.

The response of soybeans to Mo fertilization appeared to be associated with the dilute acid-extractable calcium content of the soil and with soil reaction (pH). Statistically significant increases in soybean yields were obtained from the use of Mo on soils that contained less than 1,000 ppm of calcium when soil pH values were from 5.2 to 6.2.

The effects of applications of Mo and limestone on yield of Lee soybeans grown on Calhoun silt loam–experiment 2 are presented in Table 11. On unlimed soil, the highest yield of 29.6 bushels per acre was obtained when Mo was placed on the seed. However, this treatment was not significantly better than other rates of Mo and application methods tested. The Mo seed treatment resulted in a significant yield increase of 7.4 bushels of soybeans per acre on soils that had not received lime. On plots that did not receive Mo, the use of 2 tons of limestone per acre resulted in a yield increase of 8.9 bushels of soybeans per acre. An additional increase of 6.1 bushels per acre was recorded when 4 tons of limestone were used. A total increase over the check of 15 bushels per acre was attributed to the limestone treatment at the rate of 4 tons per acre. Statistically significant yield differences were not obtained from the use of Mo where limestone was used on this soil.

Table 11.—The effects of limestone and rates and methods of placement of Mo on yield of soybeans grown on Calhoun silt loam at the Macon Ridge Branch Experiment Station, 1966

Limestone	Soil	Mo treament			
treatment	reaction	Check	Seed[1]	Foliar[2]	Soil[3]
Tons/acre	pH	— — — — — yield, bushels per acre — — — — —			
Check	5.1	A[4] 22.2 a[5]	B 29.6 a	B 28.8 a	B 29.1 a
Two	6.2	A 31.1 b	A 32.2 ab	A 34.0 b	A 34.1 b
Four	7.0	AB 37.2 c	A 34.3 b	AB 37.4 b	B 38.7 b

[1] One-half ounce Mo applied to seed immediately before inoculation and prior to planting.

[2] Three ounces of Mo applied to foliage as a spray in split applications—1½ ounces after soybeans were up to a stand and the remainder when plants were blooming.

[3] One-half pound Mo applied as a broadcast treatment to the soil.

[4] Any means within a row preceded by a capital letter in common do not differ significantly at the 5% level of probability.

[5] Any means within a column followed by a small letter in common do not differ significantly at the 5% level of probability.

Field investigations involving different rates and methods of application of Mo for soybeans were conducted on four soils at different locations in Louisiana in 1967. The soils and experimental locations were Norwood silt loam at the Dean Lee Agricultural Center, experiment 4; Commerce silt loam at the Northeast Louisiana Experiment Station, experiment 20; Crowley silt loam at the Rice Experiment Station, experiment 21; and Yahola very fine sandy loam at the Red River Valley Experiment Station, experiment 6. The effects of the Mo treatments on the yield of soybeans are presented in Table 12. On Commerce silt loam and Yahola very fine sandy loam, differences in yield due to the application of Mo were not statistically significant. The Mo seed treatment resulted in a significant reduction in the yield of soybeans on Norwood silt loam and Crowley silt loam. A reduction in stand was noted early during the growing season on the Mo-seed-treated soybeans grown on the Norwood and Crowley soils. Plants at early bloom were below normal in size, and mature top leaves contained relatively high concentrations of Mo.

Table 12.—The effects of different rates and methods of placement of Mo on the yield of soybeans, 1967

Experiment location	Soil type	Mo treatment			
		Check	Seed[1]	Foliar[2]	Soil[3]
		— — yield, bushels per acre — —			
Dean Lee Agr. Center	Norwood sil	43.6	32.6*	41.3	40.3
N.E. La. Exp. Station	Commerce sil	51.0	50.1	—	—
Rice Experiment Station	Crowley sil	31.6	25.1*	32.3	31.3
R. R. Valley Exp. Sta.	Yahola vfsl	45.4	41.9	46.0	45.1

*Differences in yield were significant at the 5% level of probability.

[1] One-half ounce of Mo applied to the seed prior to planting.

[2] Three ounces of Mo applied to the foliage.

[3] One-half pound of Mo broadcast on the soil before planting.

Four outfield investigations were conducted on soils at different locations to determine the effect of Mo on the yield of soybeans. The soils and experimental locations selected were Alligator clay in Catahoula Parish, experiment 16; Perry clay in Morehouse Parish, experiment 17; Olivier silt loam in Rapides Parish, experiment 18; and Chastain clay in Union Parish, experiment 19. With the exception of the experiment conducted in Rapides Parish on Olivier silt loam, all of the experimental areas were located on recently cleared land.

The effect of Mo on the yield of soybeans grown at the four locations is presented in Table 13. A statistically significant increase in yield resulted from the addition of Mo at two of the four locations. On Perry clay, located on the A. R. McGinty farm in Morehouse Parish, the use of Mo resulted in a yield increase of 1.1 bushels of soybeans per acre. The Mo treatment resulted in a 1.2-bushel per acre increase on Olivier silt loam on the George Tuma farm in Rapides Parish.

Soybeans grown on Chastain clay in Union Parish were not harvested for yield measurement because of very low yields which were due in part to extremely dry weather which occurred throughout the growing season.

Table 13.—The effect of Mo as a seed treatment on the yield of soybeans at four outfield locations, 1967[1]

Experiment location	Cooperator	Soil type	Soil		Yield		
			Ca	pH	No Mo	Mo[2]	Increase from Mo
Parish			ppm		— — — bushels per acre — — —		
Catahoula	La. Delta Plantation	Alligator-Perry clay	3,570	6.4	18.7	16.7	—2.0
Morehouse	A. R. McGinty	Perry clay	2,760	5.1	20.9	22.0	+1.1*
Rapides	George Tuma	Olivier-Hebert clay	560	5.6	29.9	31.1	+1.2*
Union	T. L. James & Co.	Chastain clay	750	4.1	——	——	——

*The differences in yield were significant at the 5% level of probability.

[1] Assisting with the experiments were the following Cooperative Extension Service Agents: F. O. LeVasseur, E. E. Johnson, Raymond McDuff, R. C. Whitten, and T. L. Morgan.

[2] One-half ounce of Mo was applied to the seed prior to inoculation and planting.

The effects of Mo and limestone on the yield of soybeans grown on Calhoun silt loam–experiment 2 are presented in Table 14. On unlimed soil, the highest yield, 26.7 bushels per acre, was obtained when Mo was broadcast on the soil surface. However, this treatment was not superior to the other rates of Mo and application methods tested on plots that did not receive limestone. All rates and methods of placement of Mo resulted in higher yields than were obtained on check plots. The use of Mo on unlimed soil resulted in a yield increase of from 5.6 to 6.1 bushels of soybeans per acre at the rates and methods of application of Mo that were compared.

On plots that did not receive Mo, the use of 2 tons of limestone per acre resulted in a yield increase of 4.6 bushels of soybeans per acre. An additional increase of 2.3 bushels per acre was recorded when 4 tons of limestone were used. Statistically significant yield differences were not obtained from the use of Mo where limestone was used.

Table 14.—The effects of limestone and rates and methods of placement of Mo on yield of soybeans grown on Calhoun silt loam[1] at the Macon Ridge Branch Experiment Station, 1967

Limestone treatment	Mo treatment Check	Seed[2]	Foliar[3]	Soil[4]
Tons/acre	— — — — — — — — — —	yield, bushels	per acre — — — —	— — — — — —
Check	A[5] 20.6 a[6]	B 26.2 a	B 26.2 a	B 26.7 a
Two	A 25.2 b	A 27.5 a	A 25.7 a	A 25.9 ab
Four	A 27.5 c	B 23.9 b	A 27.8 a	AB 24.4 b

[1] Initially the soil contained 74 ppm of dilute acid-extractable P, 113 ppm of K, 418 ppm of Ca, and 134 ppm of Mg. The pH of the soil was 5.1.

[2] One-half ounce of Mo was applied to the seed before inoculation.

[3] Three ounces of Mo were applied to the foliage as a spray in split applications—1.5 ounces when soybeans were up to a stand and the remainder when plants were blooming.

[4] One-half pound of Mo was applied broadcast to the soil before seeding.

[5] Any means within a row preceded by a capital letter in common do not differ significantly at the 5% level of probability.

[6] Any means within a column followed by a small letter in common do not differ significantly at the 5% level of probability.

Some agronomists consider plant tissue analysis as a valuable diagnostic technique, not only for determining critical levels of essential plant nutrients in the tissue of various crops but also to evaluate crop response to various nutrient applications.

The effects of different rates and methods of application of Mo on the Mo content of leaf tissue of soybeans grown on three different alluvial soils are presented in Table 15. The broadcast application of Mo to each of the soils resulted in the largest concentration of Mo in the leaves of the soybean plants. The leaves of plants grown on the Yahola soil at the Red River Valley Experiment Station that did not receive Mo contained a smaller amount of Mo than was found in leaves at other locations. The largest content of Mo in soybean leaves resulted from the addition of Mo to Yahola very fine sandy loam.

Table 15.—The effects of different rates and methods of application of Mo on the Mo content of leaf tissue of soybeans grown on three alluvial soils, 1967

Experiment location	Soil type	Mo treatment			
		Check	Seed[1]	Foliar[2]	Soil[3]
		— — — Mo in leaf tissue, ppm — — —			
Dean Lee Agr. Center	Norwood sil	0.85	1.76	8.65	18.48
R. R. Valley Exp. Sta.	Yahola vfsl	0.22	0.61	19.44	34.68
N.E. La. Exp. Station	Commerce sil	0.67	2.56	13.24	27.43

[1] One-half ounce of Mo per acre was applied to seed prior to inoculation and immediately before planting.

[2] One and one-half ounces of Mo per acre were applied as a spray on soybean leaves.

[3] One-half pound of Mo broadcast on soil surface before planting.

The effects of applications of limestone and Mo on the Mo content of soybean leaves grown on Calhoun silt loam, Perry clay, Crowley silt loam, and Chastain clay are presented in Table 16. The Mo content of the leaves of soybeans grown on untreated Calhoun silt loam at the Macon Ridge Experiment Station was 0.14 ppm. This concentration of Mo is considered to be low, and a yield response of about 6 bushels per acre was obtained from the use of Mo. The application of limestone to all the soils caused an increase in both native and applied Mo in the leaves of the soybean plants.

Table 16.—The effects of limestone and Mo additions on the Mo content of leaf tissue of soybeans grown on four soils in Louisiana, 1967

		Limestone treatment								
		No limestone			2 tons per acre			4 tons per acre		
		Mo treatment								
Experiment location	Soil type	Check	Seed[1]	Soil[2]	Check	Seed[1]	Soil[2]	Check	Seed[1]	Soil[2]
		Mo in leaf tissue, ppm								
Macon Ridge Exp. Sta.	Calhoun sil	0.14	0.87	0.60	0.18	0.93	2.24	0.28	0.84	4.22
Morehouse Parish, A. R. McGinty farm	Perry clay	0.84	3.10	—	0.60	1.12	—	0.93	0.84	—
Rice Exp. Station	Crowley sil	0.19	1.54	0.62	0.64	1.60	0.90	0.84	2.94	1.97
Union Parish, T. L. James & Co.	Chastain clay	0.17	0.50	—	0.16	0.29	—	0.16	0.66	—

[1] One-half ounce of Mo per acre was applied to the seed prior to inoculating and immediately before planting.

[2] One-half pound of Mo per acre was applied broadcast to the soil before planting.

The data in Table 17 indicate that raising soil pH by liming had no significant influence on the amount of Mo extracted from the soils with ammonium oxalate-oxalic acid adjusted to pH 3.3. However, soil reaction (pH) had a significant effect on the concentration of Mo in the leaves of soybean plants grown on five of the seven soils. Significantly larger concentrations of Mo were found in the leaves of plants grown on Gallion, Acadia, Jeanerette, and Crowley soils that were adjusted with limestone to pH 6.0 or higher. The data suggest that the extracting solution did not remove all of the Mo from the soil that was "available" to the plants.

Table 17.—The influence of soil reaction (pH) on extractable Mo in the soil and Mo concentration in leaves of Dare, Lee, and Bossier soybeans grown on seven soils

Experiment number	Soil type	Cultivar	Soil reaction[1]	Mo concentration Soil	Mo concentration Leaves
			pH	ppm	ppm
2	Calhoun sil	Dare	5.5	0.18	0.18
			6.7	0.16	0.26
5	Olivier sil	Lee	5.1	0.25	0.30
			6.0	0.25	0.40
7	Gallion vfsl	Dare	4.9	0.10	0.10
			6.0	0.13	0.27
8	Acadia sil	Bossier	5.7	0.25	0.34
			6.6	0.28	0.47
9	Jeanerette sil	Dare	6.0	0.30	0.12
			6.5	0.28	0.59
11	Crowley sil	Dare	5.5	0.19	0.18
			6.8	0.22	0.42
21	Crowley sil	Bossier	6.4	0.31	0.14
			7.0	0.31	0.29
LSD, 5%				ns	0.13

[1] Calcitic limestone was used on each soil to adjust the soil reaction to the higher pH value.

The effects of the different Mo treatments on the yield of soybeans grown on Norwood silt loam–experiment 4 for a 5-year period are presented in Table 18. The application of Mo to the seed, the foliage, or soil did not increase the yield of soybeans in any year. In 1967, the Mo seed treatment resulted in a significant reduction in the yield of soybeans. The reduction in yield may have been due to toxicity caused by improper mixing of the Mo material with the seed before planting. A reduction in stand was noted early during the growing season of 1967 on

Table 18.—The effects of different rates and methods of application of Mo on the yield of soybeans grown on Norwood silt loam at the Dean Lee Agricultural Center, 1965-69

Year	Mo treatment			
	Check	Seed[1]	Foliar[2]	Soil[3]
	— — — bushels per acre, average of 4 replications — — —			
1965	33.9	33.5	33.9	34.1
1966	41.1	41.3	40.5	40.6
1967	43.6	32.6*	41.3	40.3
1968	43.3	41.0	41.2	42.8
1969	46.7	43.2	44.9	44.4
5-Yr. avg.	41.7	38.3	40.4	40.4

*A statistically significant reduction in yield resulted from the Mo seed treatment in 1967.

[1] One-half ounce of Mo was applied to the seed before inoculation in 1965, 1966, and 1967. In 1968 and 1969, one-fourth ounce of Mo was used.

[2] Three ounces of Mo were applied to the foliage as a spray in split applications—1.5 ounces when soybeans were up to a stand and the remainder when the plants were blooming.

[3] One-half pound of Mo was applied broadcast to the soil before seeding.

the Mo-seed-treated soybeans. A reduction in stand was not encountered during the other years of the investigation. In 1967, soybean plants at early bloom were below normal in size and mature top leaves contained relatively high amounts of Mo.

The Mo treatments had no significant effect on the moisture content, seed weight, or germination of Lee-68 soybeans in 1969.

The effects of applications of Mo, $CaCO_3$, and $CaSO_4$ and the influence of soil reaction (pH) on the yield of Bragg soybeans grown on Wrightsville silt loam are presented in Table 19. The data show that the application of Mo alone to the soil at pH 5.0 resulted in a significant increase of 8.2 bushels of soybeans per acre. Significant yield increases were also obtained from the application of $CaCO_3$ alone at a rate of 2 tons per acre and when the $CaCO_3$ was used with $CaSO_4$ and Mo. The application of $CaCO_3$ at a rate of 1 ton per acre with $CaSO_4$ did not significantly increase the yield of soybeans. The data indicated that the response to Mo was closely related to the soil reaction (pH) and that one of the benefits derived from liming acid soils may be associated with the increase in the solubility of indigenous soil Mo. Under acid soil conditions, Mo is held tightly by soil clays and hydrated oxides of Fe and Al and thus its availability to plants may be inadequate (Hodgson, 1963).

The influence of soil reaction (pH) on the concentration of Mo in the soil and leaves of Lee soybean plants grown on Olivier silt loam is presented in Table 20. The data show that soil reaction (pH) had no significant effect on the extractable Mo concentration of the Olivier silt loam. However, soil reaction (pH) had a relatively large and signifi-

Table 19.—The effects of applications of Mo, $CaCO_3$, and $CaSO_4$ and the influence of soil reaction (pH) on the yield of Bragg soybeans grown on Wrightsville silt loam, Sherman Fontenot farm, Jefferson Davis Parish, 1971

Treatment	Soil reaction	Yield	Increase over check
	pH	– – bushels per acre	– –
Check	5.1	39.0	—
Mo[1]	5.0	47.2	8.2*
$CaCO_3$[2]	6.5	45.6	6.6*
$CaCO_3$[3], $CaSO_4$[4]	5.6	41.0	2.0
$CaCO_3$, $CaSO_4$, Mo	5.8	45.5	6.5*
LSD, 5%:		5.4	

*Denotes significance at the 5% level of probability.

[1] Mo was applied to the soil at a rate equivalent to 0.5 pound per acre as $Na_2MoO_4 \cdot 2H_2O$, 39.65% Mo.

[2] $CaCO_3$ used alone was applied at a rate of 2 tons per acre as oystershell flour, 96.7% $CaCO_3$.

[3] $CaCO_3$ used with $CaSO_4$ and Mo was applied at a rate of 1 ton per acre.

[4] $CaSO_4$ applied at a rate of 1.6 tons per acre, as gypsum, 28.4% Ca and 23.1% S.

cant influence on the Mo concentration in the leaves of the Lee soybean plants. Adjusting the soil reaction from pH 5.1 to pH 7.5 resulted in an increase from 0.41 ppm to 1.30 ppm in the concentration of Mo in the soybean leaves. The data suggest that the chemical analysis of soybean leaf tissue may be a useful "diagnostic" technique in evaluating the Mo status of the plants. Due to a relatively low concentration of extractable Mo found in many soils, together with certain errors inherent in the collection of soil samples and subsequent chemical analyses, it would be questionable whether a soil analysis for Mo would afford a good method for predicting a response to applied Mo.

Table 20.—The influence of soil reaction (pH) on the concentration of Mo in the soil and leaves of Lee soybean plants grown on Olivier silt loam—experiment 5

Reaction	Concentration of Mo	
	In soil	In leaves
pH	— — — ppm	— — —
5.1	0.26	0.41
6.0	0.25	0.40
6.7	0.29	0.50
7.2	0.27	0.65
7.4	0.29	0.86
7.5	0.29	1.30
LSD, 5%	ns	0.10

An equation based on research conducted by Mueller et al. (1964) was used to predict a yield response by soybeans to the application of Mo. The data presented in Table 21 indicate that a yield response to applied Mo was usually obtained when the soil pH + (10 x the ppm extractable Mo content of the soil) was less than 7.5. Significant yield responses to applications of Mo were obtained on nine of the 16 soils. The reaction of the soils varied from pH 4.9 to 7.6. The extractable Mo contents of the soils varied from 0.03 ppm to 0.42 ppm. The Norwood silt loam and the Yahola very fine sandy loam contained the lower amounts of extractable Mo; however, a significant yield response to Mo was not obtained on these soils. The data suggest that soil reaction (pH) together with the extractable Mo content of a soil, can be used with a reasonable degree of accuracy to predict a yield response by soybeans to applications of Mo. However, soil reaction (pH) or the extractable Mo content alone should not be used as a criterion for predicting a response. These data are in agreement with those obtained by Davies (1956) and Parker and Harris (1962), who reported that a response to Mo could be predicted if the Mo content of the soil was associated with the soil reaction (pH). Mueller et al. (1964) found that application of Mo stimulated the growth of alfalfa when the value

Table 21.—The soil reaction (pH) and extractable Mo content of the soil used to predict a yield response by soybeans to application of Mo

Experiment number	Soil type	Soil reaction	Extractable soil Mo	Soil pH + (10 x ppm extractable Mo)[1]	Measured response
		pH	ppm		
8	Acadia sil	5.7	0.05	6.2	*[2]
16	Alligator c	5.1	0.42	9.3	ns[3]
14	Calhoun sil	4.9	0.21	7.0	ns
2	Calhoun sil	5.1	0.17	6.8	*
20	Commerce sil	6.4	0.22	8.6	ns
12	Crowley sil	5.6	0.18	7.4	*
21	Crowley sil	5.9	0.14	7.3	*
11	Crowley sil	5.5	0.14	6.9	*
3	Gallion vfsl	5.3	0.04	5.7	*
7	Gallion vfsl	4.9	0.04	5.3	*
9	Jeanerette sil	5.4	0.14	6.8	*
13	Mantachie fsl	5.4	0.22	7.6	ns
4	Norwood sil	7.6	0.04	8.0	ns
17	Perry c	5.4	0.23	7.7	*
15	Robinsonville vfsl	6.2	0.18	8.0	ns
6	Yahola vfsl	7.1	0.03	7.4	ns

[1] A significant yield response was usually obtained when the soil pH + (10 x the ppm extractable Mo content of the soil) was less than 7.5.

[2] Denotes a significant difference in yield at the 5% level of probability.

[3] Denotes a nonsignificant difference in yield.

obtained by the equation soil pH + (10 x the ppm extractable Mo content of the soil) was 6.2 or less. When the calculated value was 8.2 or greater, application of Mo had no effect on the growth of alfalfa.

SUMMARY AND CONCLUSIONS

During an 8-year period (1964-1971), 22 field experiments with molybdenum (Mo) on soybeans were conducted at different locations in Louisiana to determine the effects of applications of Mo on the yield of soybeans. The Mo concentration in the leaves of soybean plants grown on the soils was also determined. An attempt was made to relate the extractable and total Mo contents of the soils to certain chemical soil properties. From the data obtained over an 8-year period, the following conclusions were drawn.

1. There was a significant increase in the yield of soybeans from the application of Mo at 11 of the 22 experiment locations. A yield response to application of Mo was obtained on soils with pH values of 4.9 to 6.0. A significant increase in the yield was not obtained on soils at a pH of 6.2 or higher. The extractable Mo content of the soils on which a significant yield response to added Mo was obtained varied from 0.04 ppm to 0.22 ppm; however, a critical concentration of Mo in the soil was not established. The data suggested that ammonium oxalate-oxalic acid was not a suitable extractant for Mo on soils that have relatively high exchange capacities.

2. Significant positive correlations were found between extractable Mo and extractable potassium, organic matter, and cation exchange capacity. A significant negative correlation was obtained between the extractable Mo content of all of the soils and the soil reaction (pH). The total Mo content of the soils was not related to extractable Mo or to the other soil chemical properties.

3. Significant increases in the yield of soybeans were obtained following application of Mo to silt loam soils when the concentration of Mo in the leaves of the plants was 0.14 ppm or below. The application of Mo or limestone resulted in significant increases in the concentration of Mo in the soybean leaves. There were no significant interactions between the applications of Mo and limestone.

4. Applications of Mo as a seed, foliar, or soil treatment proved to be equally effective in correcting Mo deficiency on the acid soils. The seed treatment was more economical, since a smaller quantity of Mo was required. However, certain precautions had to be followed in applying Mo directly to the seed. On Crowley and Norwood silt loam, the application of 0.5 ounce of Mo per acre as a seed treatment resulted in significant reductions in the stand and yield of soybeans. The stand and

yield reductions were due to an excessive amount of water used on the soybean seed at the time the Mo was added. The excess water allowed the sodium molybdate to penetrate the seed embryo and resulted in injury.

5. An equation based on soil reaction (pH) and Mo extracted from the soils with ammonium oxalate-oxalic acid was proposed to predict a yield response by soybeans to application of Mo. Evidence was presented which indicated that a response to applied Mo was usually obtained when the soil pH + (10 x the ppm extractable Mo content of the soil) was less than 7.5.

6. There appears to be a critical need for applications of limestone or Mo on many of the soils used for the production of soybeans in Louisiana. On soils with pH values below 5 the use of Mo is not recommended due to toxicities encountered from excessive amounts of manganese and possibly aluminum. The application of Mo at a rate of 0.25 ounce per acre to the seed prior to inoculation and immediately before planting soybeans on soils with pH values from 5.2 to 6.2 proved to be an efficient and inexpensive way to supply Mo to the plants. However, the Mo seed treatment was not superior to the foliar or soil treatments. Mo should not be used on soils that have been limed to pH 6.2 or higher. Under certain cropping and soil conditions, it may be more feasible to apply Mo than to lime the soil to pH 6.2. The "availability" of zinc, copper, manganese, and boron is often significantly reduced when soils are limed to above pH 6.0.

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